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EVALUATION OF +G_Z TOLERANCE FOLLOWING SIMULATED WEIGHTLESSNESS (BEDREST)

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ABSTRACT

This study was undertaken to evaluate the magnitude of physiologic changes which are known to occur in human subjects exposed to varying levels of $+G_z$ acceleration following bed rest simulation of weightlessness. Bed rest effects were documented by fluid and electrolyte balance studies, maximal exercise capability, 70° passive tilt and lower body negative pressure tests and the ability to endure randomly prescribed acceleration profiles of $+2G_z$, $+3G_z$, and $+4G_z$. Six healthy male volunteers were studied during two weeks of bed rest after adequate control observations, followed by two weeks of recovery, followed by a second two-week period of bed rest at which time an Air Force cutaway anti-G suit was used to determine its effectiveness as a countermeasure for observed cardiovascular changes during acceleration. Results showed uniform and significant changes in all measured parameters as a consequence of bed rest including a reduced ability to tolerate $+G_z$ acceleration. The use of anti-G suits significantly improved subject tolerance to all G exposures and returned measured parameters such as heart rate and blood pressure towards or to pre-bed-rest (control) values in four of the six cases.

A. Introduction

Design limitations existent in the planning of the space shuttle vehicle may be such that crew and passengers will be exposed to headward acting ($+G_z$) acceleration stresses of 2 to 4 G for periods of up to about 700 seconds. These periods of stress would occur following periods of weightlessness, i.e., exposure to a "zero" gravitational state, of various durations. Previous studies in this laboratory and elsewhere utilizing bedrest as an analog of weightlessness, have documented changes in body fluid compartments and deterioration in exercise capabilities.[1,2] These studies have also demonstrated that orthostatic hypotension and even syncope may occur upon 70° passive tilting (equivalent to a $+ 1\ G_z$ stress) following periods of simulated weightlessness, suggesting that post-bedrest exposure to even higher acceleration stresses would exaggerate the undesirable orthostatic responses. Therefore, the present study was undertaken to evaluate the magnitude of the physiologic changes which would occur in humans exposed to $+2.1\ G_z$, $+3.2\ G_z$, and $+3.8\ G_z$ stresses achieved in the human centrifuge following bedrest simulations of weightlessness. A leading hypothesis explains the observed decrease in orthostatic tolerance following weightlessness to pooling of blood and extracellular fluid in the extremities and pelvis in the presence of already diminished plasma and extracellular fluid volumes. For this reason, the modifying effect of an inflated standard Air Force cutaway G-suit on physiologic responses to these $+G_z$ stresses was evaluated.

B. Experimental Design

1. General

Healthy male volunteers, ages 24-27 years, served as subjects for this study. All volunteers were recruited from the Federal Correctional

Institution, Lompoc, California, by permission of the U.S. Bureau of Prisons. They were screened initially by the Medical Staff of F.C.I.-Lompoc to exclude major or chronic health defects, and potential volunteers were subjected to a 70° passive tilt for twenty minutes to exclude the presence of autonomic insufficiency. A tilt table with English saddle was provided to the F.C.I. staff for this purpose.

On completion of the screening procedure, the volunteers were transported to the U.S. Public Health Service Hospital, San Francisco, California, and admitted to the Metabolic Unit. A complete medical history was obtained and a complete physical examination was performed. The following laboratory tests were done and were normal: 12 lead electrocardiogram, PA and lateral chest x-rays, complete blood counts, serum sodium, potassium, CO_2, chloride, phosphate, calcium, total protein, albumin, globulin, alkaline phophatase, bilirubin, glutamic-oxalacetic-transaminase (GOT), creatinine, fasting blood glucose, blood urea nitrogen, VDRL, and complete urinalysis with microscopic examination.

The details of the study were explained to each subject verbally and in writing, and each subject signed an informed consent form.

Each volunteer was prescribed a specific metabolic diet throughout the study. The dietetic aspects of the study are covered in the detailed protocol. Eight to nine days on this diet were allowed for an equilibration period. During this time the volunteers were instructed in urine collection and in intake recording by the metabolic nurses.

The study consisted of five phases (which followed the 8-9 day diet equilibration period): a 14 day ambulatory period (A 1-14); a 15 day bedrest period (B 1-15); a 14 day recovery period (R 1-14); a second 15 day bedrest period (B'1-15); and a second 14 day recovery period (R'1-14). During the ambulatory phases the environmental

temperatures were maintained as nearly constant as possible, and no exercise except normal walking was permitted in an attempt to avoid large differences in insensible salt and water losses between the ambulatory and bedrest phases. While at bedrest, the horizontal position was required at all times with unrestricted movement in this plane. Arm movement was limited to forearm raising with elbows on the bed, and one pillow was permitted for head support. All oral consumption and all excretory activities were performed in this position. Excessive boredom was avoided by the use of radio, television, reading material, and games.

2. Detailed Protocol

a. Daily Procedures

1) Temperature, pulse, and blood pressure measurement once daily.

2) Determination of body weight on a metabolic balance immediately after completion of 7:30 AM urine collection.

3) Determination of oral fluid intake and urine output.

b. Urine Collection and Analysis

1) Twenty-four hour collections were made daily. Each voided sample was placed in a gallon container without preservative. The urinal was rinsed with 50 ml of distilled water which was also poured into the container. The sum of the rinsing volume was deducted from the total 24 hour volume to determine urine output. Total volume was utilized in calculating chemical data. All urines were refrigerated until sample aliquots were obtained, and the aliquots were frozen. Some daily aliquots were kept separate where necessary to show acute changes, and others were pooled. Pooling of the 5-7 day samples was accomplished by combining 10% volume aliquots of each sample into a single sample.

2) Urine Specimens Analysis

All samples were analyzed for Na^+, K^+, and creatinine.

c. Blood Chemistries and Hematology

Blood samples were drawn on Days A3, A9, B2, B13(or 14), R9, B'2, B'14, R'12(or 13).
These were analyzed for Na^+, K^+, and hematocrit.

d. Isotopic Volume Studies

Plasma volume was determined by ^{125}I-RISA, extracellular fluid volume by ^{82}Br, red cell mass by ^{51}Cr, and total body water by $^{3}H_2O$ on the same days as the drawing of blood samples listed above.

e. Tilt Studies

70° tilt studies were performed on Subjects 1 and 2 on Days A13, B15, R13, and B'15. Tilt studies were not performed on Subjects 3,4,5 and 6 who were subjected, instead, to lower body negative pressure (LBNP) studies (vide infra).

f. Lower Body Negative Pressure (LBNP) Studies

These studies were performed on Subjects 3,4,5 and 6 on Days A13, B15, R13, B'15, and R'14.

g. Exercise Studies

These studies were performed on Subjects 1 and 2 on Days A13, B15, R13 and B'15 following recovery from the tilt studies; and on Subjects 3,4,5 and 6 on Days A13, B15, R13, B'15, R'14 following recovery from LBNP studies.

h. Centrifuge Studies

In all subjects, three training runs were performed in the nine diet equilibration days before the start of the first ambulatory period, and formal (data) studies were performed on Days A14, R1, R14, and R'1, i.e., 24 hours following the tilt or LBNP and exercise studies.

i. Metabolic Dietetic Program

All subjects were on a specific diet for the 8-9 day diet equilibration period and throughout the entire study. Each subject selected a menu of his own choice consisting of three meals and an evening snack. The research dietician then calculated the nutrient content of the chosen menu. Distilled water intake was allowed *ad lib*, and a record of the volume consumed was recorded. The diet was well-balanced, designed to maintain the subjects' body weight, and the subjects ate all of the prescribed diet.

When particular diets were calculated to be inadequate in vitamins, supplementation was given. Specific diet details are elaborated below.

Subjects 1 and 2:

These subjects were fed a formula diet, prepared in the hospital's main kitchen, with caloric values calculated to maintain body weight. Each day the caloric intake and protein, fat, carbohydrate, sodium and potassium contents of food consumed that day were calculated from food content tables. The ranges of specific daily values are listed below:

Diet	Subject 1	Subject 2
Calories	2674 - 2983	2704 - 3066
Protein, grams	101.1 - 114.4	98.2 - 115.4
Fat, grams	130.3 - 157.0	129.4 - 140.4
Carbohydrate, grams	243.4 - 308.6	260.8 - 314.0
Sodium, milliequivalents	160.4	157.0
Potassium, milliequivalents	88.0	98.2

Subjects 3 and 4:

These subjects consumed a semi-metabolic balance diet using Armour frozen dinners for entrees. Most foods other than the frozen dinners were weighed, but a few foods (e.g., milk, bread, eggs) were not weighed. Two daily menus were used in rotation for each subject, the menus of each subject being slightly different (Tables A and B). The nutrient compositions of the diets for Subjects 3 and 4 shown in Table C were calculated from food content tables and from data furnished by Armour Laboratories. These calculated values were used as the daily intake in the calculation of sodium and potassium balances.

Subjects 5 and 6:

These subjects consumed a metabolic balance diet with three rotating menus:

Menu # 1 - served on Mondays, Wednesdays and Fridays

Menu # 2 - served on Tuesdays and Saturdays

Menu # 3 - served on Thursdays and Sundays.

The menus were the same for both subjects, and calories and sodium were calculated to be about the same on all three menus (Table D). Aliquots of the diet were analyzed for sodium and potassium on Days A5, A9, A10, B13, B14, B15, B'1, B'2, B'3, B'13, B'14, B'15; i.e., four aliquots of each of the three diets were analyzed during the study. The results of these analyses and a comparison with the calculated values are shown in Table E. The calculated and analyzed values agree quite well. The average analyzed values for the particular diet (1,2 or 3) consumed on any given day were used to calculate sodium and potassium balances.

TABLE A

MENUS FOR SUBJECT 3

	Menu # 54	Menu # 56
Breakfast	Orange juice Cornflakes Fried eggs (2) White toast (2 sl.) Butter Jelly Whole milk Sugar Pepper	Pineapple juice Oatmeal Fried eggs (2) White toast (2 sl.) Butter Jelly Whole milk Sugar Pepper
Lunch	Pot Roast Beef Dinner* (Rice, carrots, gravy) Lettuce Tomato French dressing White bread (1 sl.) Butter Applesauce Graham crackers (2) Whole milk Instant tea Sugar Pepper	Veal Patty Dinner* (Sweet potatoes, peas) Lettuce French dressing White bread (1 sl.) Butter Vanilla wafers (4) Whole milk Instant tea Sugar Pepper
Dinner	Baked Chicken Dinner* (Baked pot., Green beans with mushrooms) Lettuce Mayonnaise White bread (1 sl.) Butter Dropped cookie (1) Whole milk Instant tea Sugar Pepper	Filet Mignon Dinner* (Baked pot., Green beans with mushrooms) Lettuce Tomato Mayonnaise White bread (1 sl.) Vanilla ice cream Whole milk Instant tea Sugar Pepper
Snack	Instant coffee Canned pears	Instant coffee Canned peaches
	2.0 grams NaCl for the day	2.6 grams NaCl for the day

*Armour Frozen Dinners (Hospital Fare - Modified Diet)

TABLE B

MENUS FOR SUBJECT 4

	Menu # 53	Menu # 55
Breakfast	Orange juice Cornflakes Poached eggs (2) Whole wheat toast (2 sl.) Butter Jelly Whole milk Sugar Pepper	Pineapple juice Oatmeal Poached eggs (2) Whole wheat toast (2 sl.) Butter Jelly Whole milk Sugar Pepper
Lunch	Pot Roast Beef Dinner* (Rice, carrots, gravy) Lettuce Tomato French dressing Whole wheat bread (1 sl.) Butter Applesauce Whole milk Instant coffee Sugar Pepper	Veal Patty Dinner* (Sweet potatoes, peas) Lettuce French dressing Whole wheat bread (1 sl.) Butter Vanilla wafers (2) Whole milk Instant coffee Sugar Pepper
Dinner	Baked Chicken Dinner* (Baked pot., Green beans with mushrooms) Lettuce Mayonnaise Whole wheat bread (1 sl.) Butter Whole milk Pepper	Filet Mignon Dinner* (Baked pot., Green beans with mushrooms) Lettuce Tomato Mayonnaise Whole wheat bread (1 sl.) Butter Vanilla ice cream Whole milk Pepper
Snack	Instant coffee Sugar Canned pears	Instant coffee Sugar Canned peaches
	2.6 grams NaCl for the day	3.0 grams NaCl for the day

*Armour Frozen Dinners (Hospital Fare - Modified Diet)

TABLE C

CALCULATED NUTRIENT COMPOSITION OF SEMI-METABOLIC DIETS

Nutrient	Unit	Subject 3		Subject 4	
		Menu 54	Menu 56	Menu 53	Menu 55
Calories		2768	2770	2589	2602
Carbohydrate	grams	281.6	268.5	265.7	256.1
Fat	grams	133.2	140.4	120.5	126.9
Protein	grams	110.7	108.2	110.5	109.0
Nitrogen	grams	17.71	17.31	17.68	17.44
Calcium	mg.	1157	1251	1152	1249
	mEq.	57.73	62.42	57.48	62.32
Phosphorus	mg.	1631	1717	1725	1831
Sodium	mg.	3336	3269	3326	3278
	mEq.	145.04	142.13	144.60	142.52
Potassium	mg.	3734	3534	3795	3520
	mEq.	95.74	90.61	97.30	90.25
Magnesium	mg.	298	334	342	375
	mEq.	24.50	27.46	28.12	30.83
Iron	mg.	12.3	15.4	11.9	15.0
Vitamin A	IU	5952	10,737	5482	10,186
Thiamin	mg.	2.94	1.45	2.94	1.40
Riboflavin	mg.	3.36	2.57	3.26	2.47
Niacin	mg.	38.4	18.6	38.9	19.2
Vitamin C	mg.	152	80	152	72

TABLE D

CALCULATED NUTRIENT CONTENT OF DIETS FOR SUBJECTS 5 and 6

Nutrient	Unit	Menu Number** 1	2	3	7-day Mean
Calories		2506	2518	2493	2506
Nitrogen	grams	17.23	17.31	14.83	16.56
Protein	grams	107.7	108.2	92.7	103.5
Fat	grams	92.2	104.0	72.2	89.8
Carbohydrate	grams	290.6	268.3	350.8	301.4
Alcohol	grams	11.9	10.8	9.9	11.0
Calcium	mg.	991	1002	999	996
Phosphorus	mg.	1670	1651	1572	1636
Sodium	mEq.	129	130	130	130
Potassium	mEq.	88	77	63	77
Magnesium	mg.	269	265	319	282
Iron	mg.	18.3	13.2	12.5	15.1
Vitamin A	IU	8318	9094	8202	8506
Thiamin*	mg.	3.08	2.92	3.02	3.01
Riboflavin*	mg.	5.14	5.15	4.13	4.85
Niacin*	mg.	42.3	48.9	46.0	45.2
Vitamin C*	mg.	244	150	117	181
Vitamin D	IU	641	847	474	652
Folacin	mcg.	172	71	125	130
Vitamin B_6	mcg.	2342	2407	1107	2030
Vitamin B_{12}	mcg.	9.8	9.1	1.9	7.3
Iodine	mcg.	108	116	96	107
Cholesterol	mg.	697	606	202	530

*Values include nutrients in one Hexavitamin tablet, which was administered daily from (B13) through (R'14).

**Menu Rotation: # 1 - 3 times weekly.
2 - twice weekly
3 - twice weekly

TABLE E

DIET ANALYSIS
(meq/24 hrs)

Subjects 5 and 6

Day	Diet Number	Sodium	Potassium
A 5	3	123.8	64.2
A 9	1	134.9	82.2
A 10	2	120.8	73.5
B 13	1	135.4	81.6
B 14	2	124.5	73.1
B 15	3	124.0	65.6
B' 1	2	118.6	74.4
B' 2	3	124.6	65.2
B' 3	1	129.2	78.4
B'13	1	133.3	80.8
B'14	2	122.8	75.4
B'15	3	119.2	64.3

<u>Averages</u>

	Sodium		Potassium	
	Analyzed	Calculated	Analyzed	Calculated
Diet 1	133.2	129.0	80.8	87.6
Diet 2	121.7	130.3	74.0	77.1
Diet 3	122.9	130.1	64.8	62.8

TABLE F

MENUS FOR SUBJECTS 5 and 6

Menu # 1	Menu # 2	Menu # 3
Breakfast	Breakfast	Breakfast
Orange juice French toast (2 sl.) Butter Brown sugar w/cinnamon Whole milk Instant coffee Sugar Pepper	Tomato juice Omelet w/Bac-o-Bits Whole wheat toast (1 sl) Butter Jelly Whole milk Pepper	Grape juice Peaches (canned) Wheat Chex Whole wheat toast (1 sl) Butter Jelly Whole milk Sugar
Lunch	Lunch	Lunch
Cheeseburger White toast (2 sl) French Fried Potatoes Catsup Strawberry Shortcake (Angel cake, strawberries, Cool Whip) Coca Cola Pepper	Tuna Sandwich (1 1/2) Jello w/Mandarin oranges Vanilla wafers Lemonade Whole milk Pepper	Green Pea Soup Grilled cheese sandwich Orange sherbet Wine Cooler (Johannisberg Riesling w/Seven Up) Pepper
Dinner	Dinner	Dinner
Cabernet Sauvignon Beef Tenderloin Brown rice Asparagus (canned) Whole wheat bread (1 sl) Butter Vanilla ice cream Pepper	Spaghetti & Meatballs w/Tomato sauce Parmesan cheese Whole kernel corn (canned) Whole wheat bread (1 sl) Butter Light Choc. Cool 'n Creamy Pudding Heineken Beer Pepper	Chicken Casserole (chicken, macaroni, peas) Green beans (frozen) Whole wheat bread (1 sl) Butter Butterscotch Cool 'n Creamy pudding Cookie (1) Whole milk Pepper
Snack	Snack	Snack
Canned pears Cookie (1) Whole milk	Graham crackers w/ peanut butter Whole milk	Peanut butter & jelly sandwich Pineapple (canned)
2.5 grams NaCl for the day	0.4 grams NaCl for the day	No NaCl in a salt shaker

Sample menus for the three diets are shown in Table F.

3. Methodology

a. Biochemical Methods - All studies were performed in duplicate.

1) Sodium and potassium were determined in serum, urine, and diet by standard techniques using an Instrumentation Laboratories flame photometer, Model 143.

2) Hematocrits were determined in standard fashion. The value used was an average of duplicate determinations on seven samples of blood drawn over a six hour period.

3) Creatinine was determined in urine by use of a Technicon Autoanalyzer.

b. Multiple Isotopic Volume Studies

In the performance of multiple isotope studies on repeated occasions the total body radiation dosage was less than 150 mr/week. The method used to achieve this, and the specific methods involved in the calculation of plasma volume, extracellular fluid volume, red cell mass, and total body water have been detailed in earlier publications from this laboratory.[1]

c. 70° Tilt Studies

Tilt studies were performed on Subjects 1 and 2 after morning urine close-out. The patient was transported in the horizontal position from his room to the tilt table which was equipped with an English saddle. EKG was measured by a modified Lead II using three chest electrodes, and beat to beat heart rate was measured by a tachometer triggered by the R wave of the QRS complex. Reproducible basal heart rate and manual cuff blood

pressure measurements were made. The subject was then placed in a 70° foot down tilt. The tilt was maintained for 20 minutes unless presyncopal symptoms (symptomatic hypotension) or syncope occurred, at which time the patient was returned to the horizontal position. EKG and heart rate were recorded continuously, and blood pressure was measured every 30 seconds during the tilt and for the first five minutes of recovery; and these parameters were checked again at ten minutes following cessation of the tilt. On Day B'15 the tilt was performed with each subject wearing a G-suit inflated to 43 inches H_2O.

d. Lower Body Negative Pressure (LBNP) Studies

The LBNP studies were performed in Subjects 3,4,5 and 6 following morning urine close-out. The subject was transported to the LBNP device in a horizontal position. The lower portion of the body, from the iliac crests downward, was positioned in the LBNP box while the upper portion of the body remained on a guerney. The device used for the study was an appropriately cushioned rectangular shaped box constructed of plywood and with a rubber waist seal and sheet design as described by Wolthuis et al.[3] The vacuum was generated by a commercial vacuum cleaner, and the negative pressure measured by a Wallace & Tiernan Model FA141 differential pressure gauge. Blood pressure was measured by auscultation with a cuff above a brachial artery, and EKG from a modified chest lead. Instantaneous heart rate was derived from this EKG by a cardiotachometer and was simultaneously displayed on

an oscilloscope and continuously recorded on photographic paper. After baseline measurements of blood pressure and heart rate were stable, the subject was exposed successively to -30mmHg, -40mmHg, and -50mmHg negative pressure for periods of five minutes each. At the end of the study the vacuum was released immediately. Blood pressure was measured every 30 seconds and heart rate continuously during LBNP, and both parameters were measured at 1,2,3,4,5, and 10 minutes after return to normal atmospheric pressure. If at any time the volunteer felt presyncopal and/or the systolic blood pressure fell below 85 mmHg, the study was terminated.

e. Exercise Studies

Following completion of the 70° tilt or LBNP study, the subject was allowed to return to baseline blood pressure and heart rate values and was transferred in the horizontal position to an exercise table to which a Godart Lanooy Ergometer was attached. Four power levels were used in this study: 50 watts, 75 watts, 100 watts, and in Subjects 3,4,5 and 6 either 125, 150 or 175 watts depending on the level which was predicted to induce a heart rate in excess of 160/minute in the individual subject at that time. Each exercise level was sustained for six minutes.

When blood pressure and heart rate measurements were stable, the subject began pedaling at a rate of 50 revolutions per minute (rpm) and the ergometer was then set to the particular power level desired. Blood pressure was measured by auscultation at 3 and 6 minutes. EKG and instantaneous heart rate were continuously recorded.

At each exercise level oxygen consumption between minutes 4 through 6 was calculated from the volume of expired gas measured in a Tissot spirometer and the pO_2 of the gas measured by a Clark type oxygen electrode. Following termination of the highest exercise level the blood pressure and heart rate were recorded at 1,2,3,4,5 and 10 minutes.

f. Centrifuge Studies

One day following the tilt or LBNP and exercise studies, the subjects were transported from the USPHS Hospital, San Francisco to the NASA-Ames Research Center at Moffett Field, California, a distance of about 35 miles. During the ambulatory and recovery phases they were allowed to ambulate and to sit in a car for travel; and during the bedrest phases they were transferred from bed to guerney to ambulance bed and were kept in the horizontal position until completion of the centrifuge studies. All studies were performed between 8:30 AM and 11:30 AM with the subjects in the fasting state. Physicians were in attendance throughout the travel and study periods.

During acceleration studies ECG was measured by two sternal electrocardiographic leads connected to a cardiotachometer, temporal artery flow velocities were measured by ultrasonic flowmeters placed over both superficial temporal arteries, and blood pressure was measured manually by cuff and microphone over the left brachial artery using a Gemini sphigmomanometry system. Following placement of these devices, the subjects walked or were carried 30 feet to the Ames Biosatellite Centrifuge into which they were secured. Acceleration tolerance was assessed by a subject's response to peripheral lights presented in a random fashion, by his ability to perceive a central white light of 15 foot candles luminence, and by the presence or absence

of Doppler flow velocity signals from the superficial temporal arteries. All data were continuously recorded on a Brush 8 channel direct writing recorder and on an Ampex FR 1800 tape recorder. All subjects <u>were instructed not to perform straining maneuvers</u> during acceleration procedures. Throughout the studies voice communication was maintained, and there was constant visual monitoring of the subject by means of infrared television.

The $+G_z$ centrifuge profiles consisted of three runs separated by five to ten minute rest and equilibration periods. The runs consisted of: 1) 2.1 G for 670 seconds; 2) 3.2 G for 220 seconds; and 3) 3.8 G for 185 seconds. The rate of change of acceleration was 1.8 G per minute; and the rate of change on deceleration was about this level when the subject had completed a run uneventfully, and much faster (up to 18 G/min) when presyncope or syncope occurred. The seat back angle was adjusted just prior to the start of centrifugation, with the head upward to 30°, 19.5°, and 16.6° above the horizontal plane for the +2.1, +3.2, and +3.8 G runs, respectively, in order to maintain a full component vector of the acceleration along the long axis of the body.

At the completion of the second bedrest period of Subjects 1,2, 3 and 4, and of the first bedrest period of Subjects 5 and 6, an inflated G-suit was worn. The specific suit employed was the Air Force cutaway anti-G garment CSU-3/P inflated to 13 inches of H_2O, 45 inches of H_2O, and 60 inches of H_2O for the +2.1, +3.2, and +3.8 G_z runs, respectively. At all other times no counter-pressure device was used.

Following completion of the studies the subjects were allowed to rest and to eat or drink a portion of their metabolic diet <u>ad lib</u>.

They were then returned to the USPHS Hospital, San Francisco by car or ambulance.

C. Results

1. Analysis of Data: In this study data were accumulated on all of the parameters discussed above during all phases of the study. In evaluating the data in the different phases, attention was directed not only to the effects of the bedrest periods relative to the ambulatory control and recovery periods, but also to the recovery periods relative to the ambulatory control period. Interest in this latter aspect has been prompted by earlier studies in this laboratory which have shown that following a two week bedrest period, certain parameters may require a two week or longer recovery period to return to their ambulatory control values.[1]

In analyzing the data, group means and standard errors (95%) were calculated, and significances of values in different periods or under different circumstances were determined by use of the paired "t" test.[4] A P value of <0.05 was considered to document a significant difference.

2. General Data: Table 1 contains the height, the initial and final weights, and problems encountered by each subject during the course of the study.

3. Sodium Balance Studies: The sodium balance, calculated as the dietary sodium intake (Table 2) minus the urine sodium output (Table 3), is shown in Table 4 and Figure 1. This balance obviously disregards stool sodium and insensible sodium losses which should have been relatively constant and insignificant during all phases of this

study. Since dietary sodium intake was essentially constant, the sodium balance gives a relative estimate of extracellular fluid volume changes as reflected in urinary sodium excretion during the different phases of the study.

Table 4 and Figure 1 show that the effect of the tilt and exercise (Subjects 1 and 2) is to significantly increase positive sodium balance when compared with the previous days during both bedrest and non-bedrest phases. This same phenomenon is seen in 13 of 16 instances of LBNP and exercise in Subjects 3,4,5 and 6. Since exercise in the absence of tilt or LBNP was not performed, no conclusions can be drawn of the relative importance of exercise in inducing the sodium retention.

Table 4 also reveals a markedly negative sodium balance on Day B1 in 5 of 6 subjects and on Day B'1 in all subjects; on Day B2 in 3 of 6 subjects; and on Day B'2 in 5 of 6 subjects. The response is most marked on the first bedrest day in 9 of 12 instances and on the second bedrest day in the remaining three. Further, the initial days of recovery periods are characterized by a markedly positive sodium balance, the most markedly positive balance occurring on the first recovery day in 11 of 12 instances, and on the second recovery day in the remaining instance.

The mean values of the six subjects clearly demonstrate the increase in sodium balance on the tilt or LBNP and exercise days; the markedly negative sodium balance on the first bedrest days (R1, B'1) and the less marked but still quite negative balance on the second bedrest days (B2, B'2); the markedly positive sodium

balance on the first recovery days (R1, R'1), and less marked but still quite positive balance on the second recovery days (R2, R'2). Table 5 shows the average sodium balance per day during the different phases of the study, excluding the stress (i.e., tilt or LBNP and exercise) days at the ends of the periods. Here again the lower sodium balance in the bedrest relative to the recovery and ambulatory periods is demonstrated. These are the typical sodium balance responses to bedrest and resumption of normal upright activity which have been established in our laboratories, and document a physiologic response to the bedrest period.[1,2]

Statistical evaluation of the sodium balance during different phases of the study (Table 5 and Figure 2) shows significant decreases in sodium balance when the second bedrest period is compared with the first and second recovery periods. As expected, there are no significant differences between the ambulatory control and the first and second recovery periods. The failure of the overall results to show a significant decrease in sodium balance during the first bedrest period when compared with either the ambulatory control period or the first recovery period requires discussion. The mean daily sodium balance for Days B 1-14 was -1.9 meq/24 hrs <u>versus</u> 10.1 meq/24 hrs and 15.6 meq/24 hrs for the ambulatory control and first recovery periods, respectively. Four of the six subjects showed the proper trend. Subject 3 showed little change and Subject 1 showed a marked change to positive rather than negative sodium balance. These latter two results cause a large standard error which prevents achievement of significance. The atypical results in these subjects may have been

due to unknown or undetected variations in their diets, since neither was on a true metabolic diet. Also, it is possible that neither subject had reached full equilibration with the diet by the beginning of the ambulatory control period, since both showed the expected decrease in sodium balance during the second period of bedrest. In the case of Subject 1, the low urinary creatinine values on Days B 8-14 (Table 12) suggest inaccuracies in urine collection which would result in a higher calculated balance. These results do point up the difficulties inherent in interpreting data from small numbers of subjects in non-metabolic circumstances. Subjects 5 and 6 who received accurately evaluated metabolic diets consistently showed the expected changes in sodium balance.

4. Potassium Balance Studies: The potassium balance, Table 8 and Figure 2, is calculated from the dietary potassium intake (Table 4) minus urinary potassium excretion (Table 7). This calculation excludes stool and insensible potassium losses which are small and should be constant during all phases of the study. When the balances are calculated for each period on days when no stresses are applied to the subjects (Table 9), it is seen that the potassium balance is lower during bedrest periods when compared with the ambulatory control and recovery periods in five of the six subjects.

This decrease in potassium balance is the usual response to bedrest and recovery established in this laboratory, and has been attributed to loss of potassium from muscle breakdown during bedrest periods.[1]

These potassium balance differences achieved statistical

significance when the first bedrest period is compared with the first recovery period, and when the first recovery period is compared with the second bedrest period (Figure 2). There were no significant differences between the ambulatory control and first recovery and between the first and second recovery periods, as is expected. The failure to achieve statistical significance when the first bedrest period is compared with the ambulatory control period can be attributed to the atypical response of Subject 1. The possible reasons for the atypical response have been discussed under Sodium Balance Studies (vide supra).

5. Fluid Balance Studies: The results of fluid balance studies, i.e., oral intake minus urine output, are shown in Tables 10 and 11. These balances obviously neglect stool and insensible fluid losses which should have been relatively constant during all phases of the study. Table 11 and Figure 2, displaying the group means during different phases of the study, show statistically significant lower fluid balances during the two bedrest periods when compared with the ambulatory control and first recovery periods and no significant differences between the ambulatory control and recovery periods. This is the typical response to bedrest as previously documented in these laboratories.[1]

6. Urine Creatinine Studies: The results of urinary creatinine excretion determinations are shown in Table 12. The values in each subject, with few exceptions, are essentially constant throughout the study.

7. Serum Chemistries: The serum sodium and potassium values of each subject on particular study days are shown in Table 13.

These values are within normal limits in all subjects throughout the entire study.

8. Body Fluid Compartment Studies: Detailed results of plasma volume (PV), red cell mass (RCM), extracellular fluid volume (EFV), total body water (TBW), and body weight are presented in Table 14. Group means on particular study days are shown in Table 15 and in Figure 3. It is seen that the PV is the first body fluid compartment to have a statistically significant change during bedrest periods when compared to ambulatory control and recovery periods. The PV decreases by the second bedrest day (significantly in the second bedrest period) and continues to decrease throughout the bedrest periods. During recovery periods it rises to pre-bedrest values, and there are no significant differences in PV between the ambulatory control, first recovery, and second recovery periods.

The EFV and TBW also demonstrate consistent changes during bedrest periods, both decreasing. Although the decrease is measurable on the second bedrest days, the decrease achieves statistical significance only later in the bedrest periods. Thus, EFV and TBW achieve statistically significant decreases during bedrest periods more slowly than PV. As with PV, there are no significant differences in EFV and TBW between the ambulatory control and first and second recovery periods.

Red cell mass shows a consistent decrease throughout the study, attributable to blood withdrawal. The decrease between contiguous two week periods is not statistically significant. However, the decrease is significant when R9 is compared with

the mean ambulatory control value. Results of hematocrit determinations on study days are shown in Table 16.

9. Responses to 70° Tilt: The heart rate, blood pressure, and pulse pressure responses to 70° tilt are shown in Tables 17, 18, 19 and in Figure 4. It is noteworthy that the maximum heart rate achieved was much greater, and the minimum pulse pressure much lower, following the first bedrest period than on the previous ambulatory control or subsequent recovery periods. With the use of G-suits inflated to 43 inches of water in the tilts following the second bedrest period, the heart rates of both subjects were lower than during tilt in the ambulatory control, first bedrest, and recovery periods. The pulse pressure of Subject 1 during the G-suit tilt was greater than or equal to that in the ambulatory control, first bedrest, and recovery periods; whereas in Subject 2 it was in the same range as during the initial bedrest period, and well below the ambulatory control and recovery period values. Although Subject 2 experienced presyncopal symptoms during tilt following both bedrest periods, these symptoms appeared much (five minutes) later when the G-suit was used. Thus, in both patients the G-suit gave increased orthostatic tolerance in the post-bedrest state. Subject 2, however, complained of significant abdominal pain when the G-suit was inflated, and continued to have abdominal tenderness for 48 hours after the tilt. This abdominal trauma may well have contributed to the hypotensive episode during tilt.

10. Lower Body Negative Pressure (LBNP) Studies: The heart rate responses of Subjects 3,4,5 and 6 to LBNP are presented in

Tables 20, 21, 22 and 23. Reference to Table 20 and Figures 5a and 5b shows that several heart rate responses are common to all subjects. Firstly, in all subjects on all study days the average and maximum heart rates were lowest during the -30mmHg and highest during the -50mmHg periods. Secondly, comparing all levels of LBNP on all study days, it is seen that the highest average and highest maximum heart rates achieved during LBNP occur following the bedrest periods and at the highest tolerated level of negative pressure. Focusing on responses at the -50mmHg level which, being the most stressful is most likely to bring out differences in response, it is seen that the average and maximum heart rates in studies following bedrest are greater than in the ambulatory control and recovery periods in Subjects 3,4 and 5. Subject 6 experienced syncope and presyncope during his two post-bedrest studies and was, therefore, quite anxious during the last three LBNP studies. Perhaps it is for this reason that his heart rate responses are less in accord with those of the other subjects, i.e., higher during the two recovery periods than following the first bedrest period.

Statistical analysis of the group means of the maximum heart rate responses are shown in Table 23. Note that there is a significantly higher heart rate at rest as well as during all levels of LBNP during the first post-bedrest study when compared with the ambulatory control period results. During the study following the second bedrest period (B'15), the group means ±S.E.(95%) were nearly identical to those on B15 at all levels of LBNP. However, statistically significant differences with R13

were achieved only at the -50mmHg level. This suggests that not all subjects had returned to their ambulatory control status by R13. This possibility is strengthened by the fact that the group results on R13 did not differ significantly from those of B15. The fact that the group contained some subjects who had returned to control levels is suggested by the failure to show statistically significant differences between R13 and A13. The same findings exist in the comparison of B'15 with R'14 and R'14 with R13. Thus, in reviewing data from groups with a small number of subjects such as this, individual results and group means ±S.E.(95%) must be considered along with P values in the interpretation of results.

Table 24 shows that during LBNP there is a definite fall in systolic blood pressure throughout the LBNP period on all study days in Subjects 4,5 and 6, and on Days A13 and B15 in Subject 3. However, the drop is of the same magnitude following bedrest periods as during ambulatory control and recovery periods. There is no consistent change in magnitude or direction of the diastolic blood pressure in these studies, but in most instances the net result is a fall in the pulse pressure (Table 25). However, the magnitude of the pulse pressure fall is similar in the bedrest and non-bedrest studies.

11. Response to Exercise: Table 26 shows that the heart rate response to various levels of exercise is not consistently different in magnitude or direction when bedrest periods are compared with the ambulatory control and recovery periods. Neither is there a dramatic difference in oxygen consumption at various levels of

exercise during these periods (Table 27). However, when maximal oxygen uptake is calculated by linear extrapolation of heart rate and oxygen consumption data,[1,5] several correlations are seen. Table 28 and Figure 2 show significant differences in derived maximal oxygen uptake between the ambulatory control and first bedrest periods, between the first bedrest and the first recovery periods, between the first recovery and second bedrest periods, and between the second bedrest and second recovery periods. Also, there are no significant differences in these derived values between the ambulatory control and first recovery periods, and between the first and second recovery periods. Thus, cardiovascular performance, as reflected in the derived maximal oxygen uptake, appears to deteriorate during a two week bedrest period and to recover to pre-bedrest levels following a two week recovery period. This decrease in maximal oxygen uptake occurred in nine of ten measurable comparisons of post-bedrest with pre-bedrest results.

12. Centrifuge Studies: The heart rate responses to centrifugation are shown in Tables 29, 30 and 31 and in Figures 6 through 11. The maximum heart rates in all subjects at all $+G_z$ levels, with one instance excepted ($+3.8\ G_z$, Subject 2, Table 31, _vide infra_) were greater in the post-bedrest runs without G-suits than in the ambulatory control and recovery periods. Specifically, the maximum heart rates in the bedrest without G-suit runs exceeded those in the ambulatory control period runs by 20 to 48 (mean 32) at $+2.1\ G_z$, by 8 to 34 (mean 20) at $+3.2\ G_z$, and, with the one exception, by 12 to 53 (mean 25) at $+3.8\ G_z$. They likewise exceeded those in

the recovery period runs by similar values: 7 to 48 (mean 33) at +2.1 G_z, 11 to 44 (mean 24) at +3.2 G_z, and with the one exception, 20-32 (mean 24) at +3.8 G_z. When the heart rate responses in the post-bedrest runs with and without G-suits are compared, a significant effect of the G-suit on lowering heart rate is demonstrated. With the G-suit the post-bedrest maximum heart rates were lower than without G-suits by 5 to 50 (mean 24) in the +2.1 G_z runs, by 4 to 50 (mean 22) in the +3.2 G_z runs, and (with the one exception) by 0 to 40 (mean 21) in the +3.8 G_z runs. In fact, the maximum heart rates in the post-bedrest runs with G-suit were in most instances very close to, and at times lower than, those in the comparable ambulatory control and recovery period runs.

Subject 2's atypical maximum heart rate response at +3.8 G_z, i.e., lower in the bedrest without G-suit run than in the ambulatory control and recovery period runs, suggests increased vagal tone in this run. Such a response may have been related to the presyncopal symptoms which the patient had experienced in the immediately preceeding +3.2 G_z run on BR-. In Subject 4's +2.1 G_z run with G-suit, the G-suit spontaneously deflated early in the run. However, the run was completed. It is noteworthy that in this instance the heart rate response was essentially identical to that during the earlier post-bedrest without G-suit run.

Statistical analysis of the group means of the maximum heart rates during centrifuge studies are shown in Table 32 and Figure 11. Since some subjects wore the G-suit in the run following the first bedrest period (R1) and others in the run following the second bedrest

period (R'1), the post-bedrest data are evaluated on days on which a subject wore (BR+) or did not wear (BR-) the G-suit. Since the G-suit deflated during Subject 4's +2.1 G_z run on R'1, this datum is excluded from the BR+ group and added to the BR- group. Note that in the post-bedrest runs without G-suits (BR-), the maximum heart rates achieved are significantly higher than in the ambulatory control, recovery, and post-bedrest with G-suit (BR+) runs at the +2.1 G_z and +3.2 G_z levels, and higher than in the recovery and BR+ period runs at +3.8 G_z. Further, it is noteworthy that there are no significant differences in maximum heart rate response between the post-bedrest with G-suit (BR+) and the ambulatory control or recovery period runs at all $+G_z$ levels, indicating that the post-bedrest use of the G-suit in this study normalized the post-bedrest maximum heart rate response.

At the +3.8 G_z level, statistically significant higher maximum heart rates were not achieved in the post-bedrest without G-suit run relative to the ambulatory control period. Statistically, the lack of significance is attributable to Subject 3's very low maximum heart rate on A14, giving a large standard error.

Perhaps of greater practical significance than maximum heart rate response is the fact that subjects who had previously terminated the post-bedrest runs prematurely were able to tolerate the runs for significantly longer periods of time with the G-suit than without it. It permitted Subjects 2 and 6 the 5 and 54 seconds, respectively, needed to complete the +3.2 G_z run, and Subject 1 the 55 seconds to complete the +3.8 G_z run. Also, in the +3.8 G_z run it allowed

Subject 2 102 seconds and Subject 6 124 seconds longer tolerance than in the bedrest without G-suit run.

However, some complications related to the use of G-suits occurred. All subjects developed some asymptomatic petechiae of the feet and ankles, but Subjects 5 and 6 also developed painful edema of the toes and feet which gradually disappeared over a 12 hour period.

It is noteworthy that those subjects who developed visual impairment during centrifugation experienced peripheral light loss (PLL) before central light loss (CLL). However, when CLL did occur it followed PLL by only a few seconds. The one instance of loss of consciousness (Subject 6, +3.2 G_z run, R14) occurred within seconds following CLL as the subject was stating that CLL was occurring. In all instances of PLL and CLL the ultrasonic flowmeter signals had indicated zero flow for at least several seconds prior to the onset of visual impairment.

D. Discussion

This study attempted to 1) document and quantify a "bedrest effect" by metabolic studies and cardiovascular stress tests, and 2) evaluate the influence of this bedrest effect on tolerance to a specific $+G_z$ acceleration with and without the use of the G-suit. Both of these aims were achieved.

The bedrest effect was documented in several ways. The sodium balance, dependent on the renin-angiotensin-aldosterone system which is partly a gravity-activated system, was lower during bedrest periods than during periods of upright posture. The fluid balance,

dependent largely on changes in sodium balance, was also lower during bedrest periods. The potassium balance, presumably reflecting changes in body muscle mass, diminished during bedrest. The plasma volume, extracellular fluid volume, and total body water volume also decreased during bedrest periods. The maximum heart rate response to 70° tilt and LBNP, and the duration of tolerance to these stresses in those individuals who developed syncope demonstrated lower orthostatic tolerance following bedrest. Finally, the lower calculated maximum oxygen uptake from exercise studies following bedrest documents deterioration in cardiovascular performance.

The data obtained in the $+G_z$ profiles used here should accurately predict the responses of passengers re-entering the earth's atmosphere in the Space Shuttle Vehicle using an identical $+G_z$ profile following a two week exposure to the weightless environment. Specifically, some untrained passengers re-entering the earth's gravitational field at these $+G_z$ in the unprotected state will have higher heart rates and will experience visual impairment earlier than in the control state. Some passengers may even become syncopal. However, the wearing of the Air Force cutaway G-suit inflated to the pressures used here should normalize the heart rate responses and prolong the time to visual impairment in all passengers. Nevertheless, some lay personnel may still experience visual impairment or syncope. For such individuals, additional G protection, e.g., straining maneuvers or higher G-suit pressures, would have to be employed.

A most important objective, then, is the selection of persons who will be able to tolerate s specific $+G_z$ profile following specific periods of weightlessness. In the specific $+G_z$ profile used in this

study, Subjects 1,2 and 6 were unable to tolerate the acceleration stresses following the two week bedrest period in the unprotected state. Although the use of the inflated G-suit allowed Subject 1 to tolerate the $+G_z$ profile, Subjects 2 and 6 were still unable to complete it. And if catastrophes are to be avoided, persons like Subjects 2 and 6 must be identified.

Since admission into this study required an ambulatory subject to tolerate a 70° passive tilt, it is clear that this orthostatic tolerance test will not be of high enough selectivity in ambulatory subjects. Further, the fact that Subjects 3,4,5 and 6 in addition tolerated the LBNP profile used here during the ambulatory control period indicates that this test, used in ambulatory subjects, also will not be adequately selective. Following two weeks of bedrest, however, Subjects 2 and 6 were intolerant to tilt and LBNP suggesting that performance of these tests following a two week bedrest period will identify some of the people at risk. Such a long bedrest period as a screening procedure is obviously impractical. Our studies[7] have demonstrated decreases in plasma and extracellular fluid volumes, and others[8] have demonstrated diminution in 70° passive tilt tolerance which occurs within 48-72 hours of bedrest. Thus, it is possible that orthostatic tolerance tests may achieve the required selectivity after an abbreviated period of bedrest.

The heart rate responses and tolerances to centrifugation documented in this study are similar to those obtained in studies with somewhat different protocols and aims.[9,10,11] Specifically, it has been shown that $+G_z$ tolerance, measured by several endpoints,

deteriorates following periods of bedrest.[9,10] Further, the use of the inflated G-suit has been documented to give increased $+G_z$ tolerance in the control as well as the post-bedrest state;[10,11] although in the present study its use seemed to worsen petechial hemorrhages on the feet and ankles. It is possible that $+G_z$ tolerance in our subjects may have been increased to a greater extent than observed had the G-suits been tailored to the individual subject and had pressures in the G-suits been different. Others have found that subjects wearing the best fitting G-suits, inflated almost to the point of discomfort at 1 G, had the best $+G_z$ tolerance,[11,12] although specific inflation pressures have not been published. Finally, it has been observed that straining maneuvers[6] may result in increased $+G_z$ tolerance,[11] suggesting that the performance of such a maneuver in our study might have supplemented the increased $+G_z$ tolerance afforded by the inflated G-suit alone.

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TABLE 1
GENERAL DATA

Subject	Height (cm)	Weight (kg) Initial	Weight (kg) Final	Noteworthy Events During Study
1	176	65.13	64.78	
2	182	98.23	97.05	Abdominal pain and bruise from poorly fitting G suit during tilt.
3	175	79.96	80.37	
4	177	72.42	71.96	
5	185	69.54	68.10	Extensive edema and purpura of feet in post-bedrest with G suit centrifuge runs.
6	179	72.52	70.70	Same as 5.

TABLE 2

SODIUM INTAKE

(meq/24 hrs)

	Subject				
Day of Study	1	2	3	4	5 and 6
A 1	160	157	145	145	135
A 2-7	160	157	144	144	126
A 8-12	160	157	144	144	127
A 13	160	157	145	145	121
A 14	160	157	142	142	122
B 1	160	157	145	145	133
B 2	160	157	142	142	123
B 3-7	160	157	144	144	126
B 8-14	160	157	144	144	127
B 15	160	157	145	145	133
R 1	160	157	142	142	123
R 2	160	157	145	145	133
R 3-7	160	157	143	143	126
R 8-12	160	157	144	144	127
R 13	160	157	142	142	122
R 14	160	157	145	145	133
B' 1	160	157	142	142	123
B' 2	160	157	145	145	133
B' 3-7	160	157	143	143	126
B' 8-14	160	157	144	144	127
B' 15	160	157	142	142	123
R' 1	160	157	145	145	133
R' 2	160	157	142	142	122
R' 3-7	160	157	144	144	127
R' 8-13	160	157			128

TABLE 3
URINE SODIUM EXCRETION
(meq/24 hrs)

Day of Study	Subject 1	2	3	4	5	6
A 1	151	174	188	190	121	110
A 2-7	154	116	146	122	119	124
A 8-12	148	130	129	133	123	130
A 13	102+	116+	105+	88+	130+	92+
A 14	115*	75*	135*	127*	97*	83*
B 1	225	186	101	190	273	211
B 2	154	208	183	162	80	101
B 3-7	163	142	142	126	115	119
B 8-14	113	219	140	132	130	133
B 15	98+	120+	111+	93+	128+	137+
R 1	99*	59*	84*	63*	30*	52*
R 2	161	93	133	122	91	97
R 3-7	144	149	136	124	164	135
R 8-12	152	129	132	118	109	125
R 13	113+	122+	150+	100+	137+	101+
R 14	150*	85*	92*	80*	84*	69*
B' 1	239	214	169	275	189	144
B' 2	171	207	144	168	152	184
B' 3-7	165	138	126	133	118	128
B' 8-14	151	140	144	129	132	126
B' 15	117+	115+	134+	86+	72+	78+
R' 1	174*	111*	71*	58*	60*	74*
R' 2	108	115	89	72	169	101
R' 3-7	146	145	123	120	130	133
R' 8-13	159	133			119	116

*Centrifuge Day

+Tilt (Subjects 1,2) or LBNP (Subjects 3,4,5,6) and Exercise Day

TABLE 4

SODIUM BALANCE
(meq/24 hrs)

(Intake minus urine Output)

Day of Study	Subject 1	2	3	4	5	6	Mean
A 1	9	-17	-43	-45	14	25	-9
A 2-7	6	41	- 2	22	7	2	13
A 8-12	12	27	15	11	4	- 3	11
A 13	58+	41+	40+	57+	- 9+	29+	36+
A 14	45*	82*	7*	15*	25*	39*	36*
B 1	-65	-29	44	-45	-140	-78	-52
B 2	6	-51	-41	-20	43	22	- 7
B 3-7	- 3	15	2	18	11	7	8
B 8-14	47	-62	4	12	- 3	- 6	- 1
B 15	62+	27+	34+	52+	5+	- 4+	29+
R 1	61*	98*	58*	79*	93*	71*	77*
R 2	- 1	64	12	23	42	36	29
R 3-7	16	8	7	19	-38	- 9	0
R 8-12	8	28	12	26	18	2	16
R 13	47+	35+	- 8+	42+	-15+	21+	20+
R 14	10*	72*	53*	65*	49*	64*	52*
B' 1	-79	-57	-27	-133	-66	-21	-64
B' 2	-11	-50	1	-23	-19	-51	-26
B' 3-7	- 5	19	17	10	8	- 2	8
B' 8-14	9	17	0	15	- 5	1	6
B' 15	43+	42+	8+	56+	51+	45+	41+
R' 1	-14*	46*	74*	87*	73*	59*	54*
R' 2	52	42	53	70	-47	21	32
R' 3-7	14	12	21	24	- 3	- 6	10
R' 8-13	1	24			9	12	12

*Centrifuge Day

+Tilt (Subjects 1,2) or LBNP (Subjects 3,4,5,6) and Exercise Day

TABLE 5

SODIUM BALANCE
(meq/24 hrs)

	Day of Study				
Subject	A 1-12	B 1-14	R 1-12	B' 1-14	R' 1-7
1	8.8	18.2	15.0	-3.7	15.4
2	30.3	-31.4	28.5	7.6	21.1
3	1.7	2.9	13.8	4.2	33.1
4	11.8	7.8	27.2	-0.1	39.6
5	6.3	-4.5	2.9	-5.7	1.6
6	1.8	-4.5	6.0	-5.4	7.1
Mean	10.1	-1.9	15.6	-0.5	19.6
S.E.(95%)	±11.2	±17.6	±11.1	±5.7	±15.4

P Values

B	vs	A	<0.3
R	vs	B	<0.2
B'	vs	R	<0.005
R'	vs	B'	<0.01
R	vs	A	<0.2
R'	vs	R	<0.4

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TABLE 6

POTASSIUM INTAKE
(meq/24 hrs)

Day of Study	Subject 1	2	3	4	5 and 6
A 1	88	98	96	97	82
A 2-7	88	98	93	93	73
A 8-12	88	98	94	94	73
A 13	88	98	96	97	74
A 14	88	98	91	90	74
B 1	88	98	96	97	81
B 2	88	98	91	90	65
B 3-7	88	98	94	94	75
B 8-14	88	98	93	94	74
B 15	88	98	96	97	81
R 1	88	98	91	90	65
R 2	88	98	96	97	81
R 3-7	88	98	93	93	75
R 8-12	88	98	94	94	73
R 13	88	98	91	90	74
R 14	88	98	96	97	81
B' 1	88	98	91	90	65
B' 2	88	98	96	97	81
B' 3-7	88	98	93	93	75
B' 8-14	88	98	93	94	74
B' 15	88	98	91	90	64
R' 1	88	98	96	97	81
R' 2	88	98	91	90	74
R' 3-7	88	98	94	94	73
R' 8-13	88	98			76

TABLE 7

URINE POTASSIUM EXCRETION

(meq/24 hrs)

Day of Study	Subject 1	2	3	4	5	6
A 1	68	88	94	77	67	79
A 2-7	70	68	81	80	65	70
A 8-12	79	74	87	79	66	69
A 13	66+	82+	82+	84+	60+	55+
A 14	61*	55*	92*	78*	53*	64*
B 1	73	55	70	84	62	68
B 2	55	80	100	93	54	46
B 3-7	75	84	95	88	72	71
B 8-14	60	99	87	86	64	72
B 15	68+	82+	100+	93+	74+	80+
R 1	87*	52*	102*	69*	61*	48*
R 2	56	88	85	93	61	54
R 3-7	68	73	80	79	61	61
R 8-12	69	80	80	73	65	65
R 13	74+	73+	94+	60+	62+	59+
R 14	74*	52*	93*	91*	55*	56*
B' 1	72	73	68	109	61	64
B' 2	66	70	88	80	58	72
B' 3-7	76	87	82	86	71	77
B' 8-14	69	79	90	87	64	68
B' 15	63+	77+	94+	56+	52+	60+
R' 1	80*	75*	91*	68*	65*	56*
R' 2	86	74	94	65	58	51
R' 3-7	72	78	86	72	53	45
R' 8-13	73	75			65	62

*Centrifuge Day

+Tilt (Subjects 1,2) or LBNP (Subjects 3,4,5,6) and Exercise Day

TABLE 8

POTASSIUM BALANCE
(meq/24 hrs)

(Intake minus urine Output)

	Subject						
Day of Study	1	2	3	4	5	6	Mean
A 1	20	10	2	20	15	3	12
A 2-7	18	30	12	13	8	6	14
A 8-12	9	24	7	15	7	4	11
A 13	22+	16+	14+	13+	14+	19+	16+
A 14	27*	43*	- 1*	12*	21*	10*	19*
B 1	15	43	26	13	19	13	22
B 2	33	18	- 9	- 3	11	19	12
B 3-7	13	14	- 1	6	3	4	6
B 8-14	28	- 1	6	8	10	2	9
B 15	20*	16+	- 4+	4+	7+	1+	7+
R 1	1*	46*	-11*	21*	4*	17*	13*
R 2	32	10	11	4	20	27	17
R 3-7	20	25	13	14	14	14	17
R 8-12	19	18	14	21	8	8	15
R 13	14+	25+	- 3+	30+	12+	15+	16+
R 14	14*	46*	3*	6*	26*	25*	20*
B' 1	16	25	23	-19	4	1	8
B' 2	22	28	8	17	23	9	18
B' 3-7	12	11	11	7	4	- 2	7
B' 8-14	19	19	3	7	10	6	11
B' 15	25+	21+	- 3+	34+	12+	4+	16+
R' 1	8*	23*	53*	29*	16*	25*	26*
R' 2	2	24	- 3	25	16	23	14
R' 3-7	16	20	8	22	20	28	19
R' 8-13	15	23			11	14	16

*Centrifuge Day

+Tilt (Subjects 1,2) or LBNP (Subjects 3,4,5,6) and Exercise Day

TABLE 9

POTASSIUM BALANCE
(meq/24 hrs)

Subject	Day of Study				
	A 1-12	B 1-14	R 1-12	B' 1-14	R' 1-7
1	14.9	22.0	19.2	16.3	12.7
2	26.3	9.0	22.9	17.7	20.9
3	8.4	3.6	10.9	7.5	5.9
4	14.7	6.8	17.1	6.0	23.7
5	9.0	8.0	11.1	8.0	18.9
6	5.6	5.1	12.6	3.1	26.9
Mean	13.2	9.1	15.6	9.8	18.2
S.E.(95%)	±7.78	±6.95	±5.14	±6.16	±8.06

<u>P Values</u>

B vs A	<0.30
R vs B	<0.05
B' vs R	<0.01
R' vs B'	<0.20
R vs A	<0.20
R' vs R	<0.50

TABLE 10

FLUID BALANCE SUMMARY
(ml/24 hrs)

	Subject					
Day of Study	1	2	3	4	5	6
A 1	828	732	-209	390	901	1136
A 2	1129	179	278	-23	807	162
A 3	706	1581	558	404	780	390
A 4	878	852	381	91	840	425
A 5	104	404	225	665	331	701
A 6	1191	581	381	841	471	411
A 7	711	1027	661	699	600	675
A 8	1198	524	236	411	242	152
A 9	-327	961	446	-329	-16	-269
A 10		562	71	391	456	464
A 11	900	769	560	-280	725	60
A 12	1207	852	390	566	656	911
A 13	1886	1621	530	45	806	-4
A 14			191	466	465	710
B 1	248	585	1198	-510	-288	-518
B 2	869	-70	518	54	693	666
B 3	425	-231	-730	420	191	-369
B 4	597	470	506	336	695	410
B 5	499	200	760	630	236	186
B 6	265	59	676	261	-589	-39
B 7	431	-435	-680	-60	1085	445
B 8	679	-60	951	446	-1159	-129
B 9	805	689	25	-10	211	351
B 10	409	-35	-164	-4	156	-29
B 11	949	340	120	40	830	5
B 12	255	119	696	166	211	851
B 13	157	167	766	71	477	172
B 14	493	285	582	271	379	543
B 15	801	-687	857	487	446	481

TABLE 10
FLUID BALANCE SUMMARY
(ml/24 hrs)

Day of Study	Subject 1	2	3	4	5	6
R 1			1616	846	841	961
R 2	1109	995	-420	145	981	1051
R 3	645	559	-379	1086	375	235
R 4	1017	685	155	-20	-129	391
R 5	834	780	536	221	-274	-14
R 6	1235	-71	30	265	925	275
R 7	841	678	466	126	-279	451
R 8	858	1283	876	326	827	763
R 9	234	661	720	325	786	670
R 10	1396	613	515	575	405	75
R 11	868	613	236	796	231	816
R 12	340	719	380	595	521	-9
R 13	1190	1713	-132	388	-424	706
R 14			1125	515	280	725
B' 1	205	-431	107	-1683	-518	712
B' 2	544	133	637	407	269	-306
B' 3	398	-447	506	811	80	-165
B' 4	515	1149	905	280	426	-39
B' 5	876	688	676	186	391	-89
B' 6	848	723	55	-260	565	390
B' 7	975	174	296	11	221	-599
B' 8	376	428	80	155	211	861
B' 9	258	303	336	-674	61	166
B'10	1325	-91	755	-185	290	345
B'11	1031	1828	946	331	301	-19
B'12	398	213	335	235	661	201
B'13			-263	12	6	511
B'14			484	-989	370	465
B'15			414	669	761	796

TABLE 11

FLUID BALANCE SUMMARY
(ml/24 hrs)

	Day of Study			
Subject	A 1-12	B 1-14	R 1-12	B' 1-12
1	775	506	853	646
2	752	149	683	389
3	332	373	395	470
4	318	151	441	-32
5	566	224	434	247
6	435	182	472	121
Mean	530	264	546	307
S.E.(95%)	±211.8	±151.9	±190.5	±257.6

P Values

B	vs	A	<0.05
R	vs	B	<0.025
B'	vs	R	<0.05
R	vs	A	<0.7

TABLE 12
URINE CREATININE
(mgm/24 hrs)

Day of Study	Subject 1	2	3	4	5	6
A 1-7	1770	2066	2355	2037	1943	1923
A 8-13	1864	2179	2338	1952	1971	1922
A 14	1789	2253	2345	2047	1961	2002
B 1-7	1833	2316	2376	2097	1946	1965
B 8-14	1554	2613	2409	2113	1950	2011
B 15	1808	2267	2446	2260	1965	1788
R 1	1915	1647	2501	1895	1977	1915
R 2-7	1808	2337	2360	1953	1986	1987
R 8-12	1917	2384	2283	1930	1961	2054
R 13	1788	2326	2232	1878	1959	1918
R 14	1777	1875	2512	2071	1895	1796
B'1-7	1800	2276	2374	2079	1901	2039
B'8-14	1807	2317	2346	2081	1938	2053
B'15	1773	2266	2326	2018	1997	1974
R'1	1829	2332	2483	1945	2357	2062
R'2-7	1860	2247	2362	1943	2013	1968

TABLE 13
SERUM CHEMISTRIES

Subject	Day of Study	Sodium meq/L	Potassium meq/L
1	A 3	138	4.0
	A 9	138	4.0
	B 2	139	4.1
	B 13	142	4.6
	R 9	140	4.0
	B' 2	140	4.5
	B'14	140	4.3
	R'12	140	4.0
2	A 3	138	3.7
	A 9	138	3.8
	B 2	138	4.0
	B 13	139	3.7
	R 9	138	3.9
	B' 2	138	4.0
	B'14	137	3.8
	R'12	140	4.3
3	A 3	137	4.4
	A 9	138	4.6
	B 2	136	4.8
	B 14	138	4.8
	R 9	137	4.6
	B' 2	137	4.8
	B'14	136	4.9

TABLE 13
SERUM CHEMISTRIES

Subject	Day of Study	Sodium meq/L	Potassium meq/L
	A 3	138	4.9
	A 9	139	4.2
	B 2	139	4.8
4	B 14	140	5.0
	R 9	140	4.7
	B' 2	140	5.2
	B'14	138	4.2
	A 3	140	4.0
	A 9	141	3.9
	B 2	141	4.4
5	B 14	140	4.3
	R 9	143	4.2
	B' 2	143	4.3
	B'14	141	4.4
	R'12	140	4.0
	A 3	139	3.8
	A 9	139	3.9
	B 2	139	3.8
	B 14	140	3.9
6	R 9	142	3.8
	B' 2	140	3.9
	B'14	141	4.2
	R'12	142	4.5

TABLE 14

BODY FLUID COMPARTMENTS

Subject	Day of Study	Plasma Volume (ml)	Red Cell Mass (ml)	Extracellular Fluid Volume (L)	Total Body Water (L)	Weight (kg)
	A 3	3136	1917	14.75	41.00	65.11
	A 9	2904		14.13	39.91	64.48
	B 2	2720		13.70	39.35	63.26
	B 14	2603	2018	13.84	38.96	63.06
1	R 9	3255	1926	15.10	39.32	63.49
	B' 2	2931	1826		38.59	63.54
	B'14	2636	1838	14.45	37.68	63.08
	R'12	3234	1924	15.38	41.36	64.78
	A 3	3474	2249	19.07	50.56	98.23
	A 9	3484	2215	19.04	49.23	98.43
	B 2	3471	2051	19.17	49.91	98.47
	B 14	3283	2204	18.04	48.73	97.38
2	R 9	3738	2084	19.75	49.41	97.34
	B' 2	3384	2105			97.23
	B'14	3230	2096	18.62	48.56	96.96
	R'12	3644	2099	19.40	51.43	97.05
	A 3	3375	2028	20.00	52.06	79.96
	A 9	3181	1984	20.20	52.04	79.48
	B 2	4078	1990	20.08	52.74	80.38
	B 14	3252	1976	19.12	50.32	79.57
3	R 9	3384	1831	20.56	51.36	79.37
	B' 2	3332	1870	20.19	50.05	79.26
	B'14	3198	1910	19.65	49.87	79.46
	R'13	3437	1786	21.25	52.17	80.37

TABLE 14
BODY FLUID COMPARTMENTS

Subject	Day of Study	Plasma Volume (ml)	Red Cell Mass (ml)	Extracellular Fluid Volume (L)	Total Body Water (L)	Weight (kg)
	A 3	3543	2024	17.57	46.53	72.42
	A 9	3763	1994	17.52	47.99	72.77
	B 2	3306	1946	16.50	46.74	71.43
	B 14	3465	1922	16.34	46.24	71.45
4	R 9	3537	1782	17.08	47.28	71.23
	B' 2	3407	1812	16.47	45.20	70.15
	B'14	3392	1743	16.47	45.71	70.19
	R'13	3914	1670	18.41	46.38	71.96
	A 3	3249	1892	15.40	44.01	69.54
	A 9	3297	1844	15.67	42.44	68.82
	B 2	2857	1794	14.18	43.44	68.03
	B 14	2880	1726	14.56	42.02	68.00
5	R 9	3585	1705	15.16	45.50	67.68
	B' 2	3184	1738	15.19	42.27	68.00
	B'14	2768	1670	14.98	41.95	67.71
	R'12	3071	1695	14.65	41.94	68.10
	A 3	3597	1945	16.80	46.66	72.52
	A 9	3526	1963	17.06	44.06	72.38
	B 2	3354			43.30	71.62
	B 14	3157	1790	16.53	41.43	71.04
6	R 9	3362	1722	16.52	44.32	71.26
	B' 2	3225	1710	16.40	45.58	71.81
	B'14	2932	1696	16.07	43.69	70.35
	R'12	3362	1672	16.26	43.97	70.70

TABLE 15

BODY FLUID COMPARTMENTS

Group Mean ± S.E.(95%)

Day of Study	Plasma Volume (ml)	Red Cell Mass (ml)	Extracellular Fluid Volume (L)	Total Body Water (L)
A 3	3396 ±186	2009 ±136	17.26 ±2.14	46.80 ±4.28
A 9	3359 ±315	2000 ±167	17.27 ±2.31	45.94 ±4.79
B 2	3142 ±411	1945 ±174	16.73 ±3.56	45.91 ±5.13
B 14	3107 ±328	1939 ±179	16.40 ±2.10	44.62 ±4.72
R 9	3477 ±184	1842 ±150	17.36 ±2.42	46.20 ±4.44
B' 2	3244 ±185	1844 ±148	17.06 ±3.45	44.34 ±5.28
B'12	3026 ±309	1826 ±168	16.71 ±2.14	44.58 ±4.70
R'14	3444 ±315	1808 ±181	17.56 ±2.68	46.21 ±4.91

P VALUES

B 2 vs A*	<0.07	<0.10	<0.10	<0.40
B 14 vs A*	<0.01	<0.20	<0.001	<0.02
R 9 vs A*	<0.40	<0.01	<0.80	<0.80
B'2 vs R 9	<0.02	<0.95	<0.20	<0.20
B'14 vs R 9	<0.01	<0.60	<0.005	<0.02
R'12 vs R 9	<0.80	<0.20	<0.60	<0.995

$^{*}A = \dfrac{A\ 3 + A\ 9}{2}$

TABLE 16

HEMATOCRITS

	Subject					
Study Day	1	2	3	4	5	6
A 3	46.6	46.5	46.3	44.0	43.9	42.3
A 9	46.4	46.0	45.8	41.9	43.1	42.7
B 2	47.3	45.1	46.1	44.5	45.5	43.2
B 14	50.4	49.5	47.2	43.8	44.6	43.3
R 9	43.9	43.4	44.5	40.7	42.5	40.8
B' 2	46.9	44.3	44.6	42.5	44.2	42.0
B'14	47.4	45.6	45.3	41.2	44.2	43.4
R'12	44.0	44.1	41.2	35.7	43.6	40.2

TABLE 17

HEART RATE RESPONSE TO 70° TILT AND RECOVERY
(Beats/min)

Subject	Day of Study	Termination Time (min)	Baseline	Tilt Time (min)				Recovery Time (min)		
				5	10	15	Final	1	5	10
1	A 13	20	62	90	95	100	105	80	60	70
	B 15	20	66	100	106	120	128	84	69	69
	R 13	20	51	78	78	89	85	56	53	54
	B'15 (with G suit)	20	55	60	66	67	78	63	71	64
2	A 13	20	69	102	104	112	110	55	60	75
	B 15	12*	93	122	132		124	127	76	74
	R 13	20	69	107	104	110	110	65	60	69
	B'15 (with G suit)	17**	69	92	96	98	67	67	64	62

*Nausea, spots in front of eyes.

**Blood pressure fall to 80/78 with nausea and abdominal pain induced by G-suit.

TABLE 18

BLOOD PRESSURE RESPONSE TO 70° TILT AND RECOVERY
(mmHg)

				Tilt Time (min)				Recovery Time (min)		
Subject	Day of Study	Termination Time (min)	Baseline	5	10	15	Final	1	5	10
1	A 13	20	112/73	106/90	105/95	106/93	110/95	120/85	122/80	122/85
	B 15	20	115/85	105/96	102/90	96/88	104/97	112/76	122/82	114/82
	R 13	20	113/81	108/88	114/90	110/86	106/88	110/78	124/86	110/75
	B'15 (with G suit)	20	114/75	122/96	124/100	126/102	116/98	120/90	120/92	124/86
2	A 13	20	119/68	104/78	96/78	96/80	92/78	126/76	112/78	106/74
	B 15	12*	115/69	100/76	76/68		70/60	106/78	120/90	112/78
	R 13	20	117/70	106/90	102/84	102/86	104/88	114/76	112/78	105/80
	B'15 (with G suit)	17**	119/86	114/96	102/92	96/86	80/78	85/70	108/94	118/90

*Nausea, spots in front of eyes.

**Blood pressure fall to 80/78 with nausea and abdominal pain induced by G-suit.

TABLE 19

PULSE PRESSURE RESPONSE TO 70° TILT AND RECOVERY

Subject	Day of Study	Termination Time (min)	Baseline	Tilt Time (min) 5	10	15	Final	Recovery Time (min) 1	5	10
1	A 13	20	39	26	20	13	15	35	42	37
	B 15	20	30	9	12	8	7	36	40	32
	R 13	20	32	20	24	24	18	32	38	35
	B'15 (with G suit)	20	39	26	24	24	18	30	28	38
2	A 13	20	51	26	18	16	14	50	34	32
	B 15	12*	46	24	8		10	28	30	34
	R 13	20	47	16	18	16	16	38	34	25
	B'15 (with G suit)	17**	33	18	10	10	2	15	14	28

*Nausea, spots in front of eyes.

**Blood pressure fall to 80/78 with nausea and abdominal pain induced by G-suit.

TABLE 20

HEART RATE RESPONSE TO LBNP AND RECOVERY
(Beats/min at each minute)

			LBNP Magnitude															Recovery		
	Day of		-30mmHg					-40mmHg					-50mmHg							
Subject	Study	Baseline	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	5	10
	A 13	49	50	54	53	50	51	60	54	52	56	47	57	69		80	70	55	56	55
	B 15	57	57	66	66	60	63	67	70	83	69	74	96	93	105	82	92	45	46	59
3	R 13	50	56	64	61	61	60	69	76	76	80	78	80	78	75	78	84	53	56	72
	B'15	51	58	55	52	52	50	56	58	55	58	61	62	77	80	101	82	50	46	50
	R'14	55	50	53	47	48	49	54	49	50	50	49	54	56	54	58	56	53	46	48
	A 13	45	63	52	61	66	66	68	79	65	70	69	85	86	81	81	94	58	53	49
	B 15	51	62	74	78	76	78	91	98	91	92	97	105	105	110	115	+	40	49	50
4	R 13	54	53	65	58	62	62	69	69	68	66	69	78	81	78	82	86	58	51	56
	B'15	52	63	72	67	70	67	77	77	85	82	77	98	94	103	102	96	50	50	49
	R'14	50	50	59	71	64	56	72	76	57	62	58	86	76	78	85	77	41	50	49
	A 13	48	50	50	50	55	52	57	62	72	62	65	65	67	72	65	70	55	47	55
	B 15	52	53	60	63	62	61	73	73	80	78	78	91	86	90	99	95	40	51	44
5	R 13	48	46	50	47	49	49	51	53	55	73	60	63	70	87	93	75	46	54	48
	B'15	49	62	61	67	65	67	69	84	85	84	79	79	84	100	102	108	43	42	45
	R'14	52	45	51	55	50	63	52	56	54	57	64	71	63	82	72	80	49	49	45
	A 13	47	47	55	52	55	58	63	60	69	57	68	64	84	70	73	82	55	49	44
	B 15	48	67	68	70	64	61	82	80	88	86	82	87	100	60*			47	55	46
6	R 13	63	70	67	77	79	68	80	92	87	96	77	89	91	101	96	103	68	57	75
	B'15	54	67	84	87	86	83	104	110	110	55**							49	47	50
	R'14	56	72	90	68	72	69	81	84	86	82	95	108	101	98	110	90	53	46	53

*Syncope.
**Nausea, pallor, hypotension.
+Technical failure.

TABLE 21

AVERAGE HEART RATE+ DURING LBNP

(Beats/min)

Subject	Day of Study	Rest	LBNP Magnitude -30mmHg	-40mmHg	-50mmHg
	A 13	49	52	54	69
	B 15	57	62	73	94
3	R 13	50	60	76	79
	B'15	51	53	58	80
	R'14	55	49	50	56
	A 13	45	62	70	85
	B 15	51	74	94	109
4	R 13	54	60	68	81
	B'15	52	68	80	99
	R'14	50	60	65	80
	A 13	48	51	64	68
	B 15	52	60	76	92
5	R 13	48	48	58	78
	B'15	49	64	80	95
	R'14	52	53	56	74
	A 13	47	53	63	75
	B 15	48	66	84	94*
6	R 13	63	72	86	96
	B'15	54	81	108**	
	R'14	56	74	86	101

*Syncope.

**Nausea, pallor, hypotension.

+Calculated as the average of the heart rates at each minute during each level of LBNP.

TABLE 22

MAXIMUM HEART RATE DURING LBNP
(Beats/min)

Subject	Day of Study	Rest	LBNP Magnitude -30mmHg	-40mmHg	-50mmHg
	A 13	49	54	60	80
	B 15	57	66	83	105
3	R 13	50	64	80	84
	B'15	51	58	61	101
	R'14	55	53	54	58
	A 13	45	66	79	94
	B 15	51	78	98	115
4	R 13	54	65	69	86
	B'15	52	72	85	103
	R'14	50	71	76	86
	A 13	48	55	72	72
	B 15	52	63	80	99
5	R 13	48	50	73	93
	B'15	49	67	85	108
	R'14	52	63	64	82
	A 13	47	58	69	84
	B 15	48	70	88	100*
6	R 13	63	78	96	101
	B'15	54	87	110**	
	R'14	56	90	95	110

*Syncope.

**Nausea, pallor, hypotension.

Table 23

Maximum Heart Rate During LBNP
Group Means ±S.E.(95%)
(beats/minute)

		LBNP Magnitude		
Day of Study	Rest	-30mmHg	-40mmHg	-50mmHg
A 13	47 ±2.7	58 ±8.6	70 ±13	82 ±15
B 15	52 ±5.9	69 ±10	87 ±13	105 ±12
R 13	54 ±11	64 ±18	80 ±19	91 ±12
B'15	52 ±3.3	71 ±19	85 ±32	104 ±9
R'14	53 ±4.4	69 ±25	72 ±28	84 ±34

<u>P Values</u>

B vs A	<0.05	<0.005	<0.02	<0.005
R vs B	<0.8	<0.4	<0.4	<0.2
B' vs R	<0.5	<0.3	<0.6	<0.005
R' vs B'	<0.3	<0.4	<0.05	<0.10
R vs A	<0.2	<0.4	<0.4	<0.3
R' vs R	<0.9	<0.5	<0.4	<0.5

TABLE 24

BLOOD PRESSURE RESPONSE TO LBNP AND RECOVERY
(mmHg)

Subject	Day of Study	Termination Time (min)	Baseline	LBNP Magnitude -30mmHg 5 min.	LBNP Magnitude -40mmHg 5 min.	LBNP Magnitude -50mmHg 5 min.	Terminal	Recovery 1 min.	Recovery 5 min.	Recovery 10 min.
	A 13	15	121/81	98/70	118/68	106/80		130/80	130/84	120/74
	B 15	15	127/71	120/80	110/80	116/80		126/90	138/90	140/100
3	R 13	15	99/61	105/75	105/80	98/80		115/70	115/80	110/70
	B'15	15	128/70	130/80	120/80	130/70		146/88	148/90	146/80
	R'14	15	121/87	110/88	110/80	118/70		126/80	125/85	120/85
	A 13	15	112/75	98/68	106/70	100/78		110/76	112/72	110/80
	B 15	14+	117/70	110/80	95/80		95/80	140/80	130/80	120/70
4	R 13	15	135/75	110/75	110/75	100/80		115/85	135/80	135/85
	B'15	15	117/73	120/80	110/80	100/90		135/80	140/90	120/80
	R'14	15	101/58	92/62	92/60	80/58		108/70	102/60	104/70
	A 13	15	119/68	108/80	106/84	108/80		110/82	112/68	120/70
	B 15	15	118/70	104/74	110/76	90/80		120/90	130/84	120/80
5	R 13	15	121/90	106/78	110/80	100/86		122/80	122/90	116/80
	B'15	15	102/67	104/74	102/78	94/72		120/82	120/84	114/82
	R'14	15	125/73	122/80	110/80	106/80		116/80	128/80	112/76
	A 13	15	103/60	100/40	90/50	84/64		92/60	106/60	102/72
	B 15	12*	115/70	100/72	100/80		80/50	100/70	116/70	112/70
6	R 13	15	111/90	96/70	104/80	92/78		96/70	110/80	108/78
	B'15	8**	136/83	104/78			78/56	125/75	128/80	124/80
	R'14	15	118/71	106/76	94/74	96/74		116/76	112/70	92/54

*Syncope.

**Nausea, pallor, hypotension.

+Technical failure.

TABLE 25

PULSE PRESSURE RESPONSE TO LBNP AND RECOVERY

(mmHg)

Subject	Day of Study	Termination Time (min)	Baseline	LBNP Magnitude -30mmHg 5 min	-40mmHg 5 min	-50mmHg 5 min	Terminal	Recovery 1	5	10
	A 13	15	40	18	50	28		50	46	46
	B 15	15	56	40	30	36		36	48	40
3	R 13	15	38	30	25	18		45	35	40
	B'15	15	58	50	40	50		58	58	66
	R'14	15	34	22	30	48		46	40	35
	A 13	15	37	30	36	22		34	40	30
	B 15	14+	47	30	15		15	15	50	50
4	R 13	15	60	35	35	20		30	55	50
	B'15	15	44	40	30	10		55	50	40
	R'14	15	43	30	32	22		38	42	34
	A 13	15	51	28	22	28		28	44	50
	B 15	15	48	30	34	10		30	46	40
5	R 13	15	31	28	30	14		42	32	36
	B'15	15	35	30	24	22		38	36	32
	R'14	15	52	42	30	26		36	48	36
	A 13	15	43	60	40	20		32	46	30
	B 15	12*	45	28	20		30	30	46	42
6	R 13	15	21	26	24	14		26	30	30
	B'15	8**	53	26			22	50	48	44
	R'14	15	47	30	20	22		40	42	38

*Syncope.

**Nausea, pallor, hypotension.

+Technical failure.

TABLE 26

HEART RATE RESPONSE TO EXERCISE AND RECOVERY
(Beats/min)

		Exercise Level							Recovery Time (min)					
Subject	Day of Study	Rest	50W	75W	100W	125W	150W	175W	1	2	3	4	5	10
1	A 13	60	100	120	140				100	100	90	90	86	80
	B 15	72	99	127	136				115	105	97	90	92	90
	R 13	60	107	106	126				94	90	74	75	78	66
	B'15	57	81	115	140				95	86	86	76	88	80
2	A 13	68	100	114	120				85	85	72	80	80	72
	B 15	82	106	120	140				104	107	94	89	95	96
	R 13	66	94	111	121				85	86	80	80	74	78
	B'15	62	88	107	126				90	80	79	80	76	77
3	A 13	53	92	112	143				88	81	68	61	61	56
	B 15	58	90	110	140				87	64	69	65	69	57
	R 13	56	87	115	142				93	90	73	67	72	60
	B'15	48	78	100	129		167		123	97	93	82	82	80
	R'14	47	77	106	128		167		118	96	97	82	70	90

TABLE 26

HEART RATE RESPONSE TO EXERCISE AND RECOVERY
(Beats/min)

Subject	Day of Study	Exercise Level							Recovery Time (min)					
		Rest	50W	75W	100W	125W	150W	175W	1	2	3	4	5	10
	A 13	52	82	102	124				68	68	83	90	66	65
	B 15	49	85	119	145				111	108	100	84	76	67
4	R 13	52	86	120	127				74	90	67	67	66	76
	B'15	52	83	114	147		173		130	108	100	94	96	92
	R'14	53	85	102	128		170		146	117	107	109	108	103
	A 13	47	84	98	120			177	154	125	113	106	100	91
	B 15	54	78	92	130		172		141	120	98	97	88	80
5	R 13	55	88	115	133		168		132	104	103	97	94	82
	B'15	46	78	109	144		177		146	124	114	106	102	97
	R'14	48	76	100	120			172	141	117	105	92	90	82
	A 13	45	92	96	123		177		145	122	100	84	76	71
	B 15	70	88	107	137	168			144	122	100	102	102	88
6	R 13	60	88	100	125		176		158	141	120	117	99	79
	B'15	56	96	115	145	172			144	122	101	92	89	90
	R'14	52	90	108	138		178		164	145	124	109	96	85

TABLE 27

RESPONSE TO EXERCISE: OXYGEN CONSUMPTION

(ml/min)

Subject	Day of Study	Baseline	50W	75W	100W	125W	150W	175W
1	A 13	264	850	*	*			
	B 15	248	*	1168	1505			
	R 13	212	940	1234	1541			
	B'15	250	866	1177	1477			
2	A 13	290	947	1271	1628			
	B 15	280	953	1272	1662			
	R 13	316	954	1272	1627			
	B'15	297	954	1156	1670			
3	A 13	178	950	1180	1571			
	B 15	194	882	1134	1464			
	R 13	184	*	1168	*			
	B'15	240	894	1103	1234		2250	
	R'14	226	931	1261	1595		2370	
4	A 13	192	1006	1320	1714			
	B 15	190	920	1247	1557			
	R 13	188	862	1297	1577			
	B'15	241	902	1220	1551		1989	
	R'14	253	949	1175	1614		2396	
5	A 13	144	955	1203	1604			2600
	B 15	197	875	1103	1561		2271	
	R 13	219	884	1279	1844		2562	
	B'15	217	761	1220	1698		2197	
	R'14	256	853	1251	1604			2869
6	A 13	218	938	1256	1592		2507	
	B 15	200	921	1189	1654	1991		
	R 13	234	1003	1205	1777		2654	
	B'15	186	864	1231	1577	2023		
	R'14	218	901	1298	1763		2681	

*Technical inaccuracies in gas collection.

TABLE 28
DERIVED MAXIMAL OXYGEN UPTAKE
(ml/min)

Subject	Day of Study				
	A 13	B 15	R 13	B' 15	R' 14
1	*	2268	2677	2146	
2	3011	2679	2947	2788	
3	2184	2185	*	2315	2617
4	2829	2156	2491	2104	2564
5	2708	2455	2742	2265	2999
6	2601	2256	2854	2161	2612
Mean	2667	2333	2742	2296	2698
S.E.(95%)	±384.7	±208.8	±216.5	±265.9	±321.6

*Data inadequate for accurate calculation.

P Values

A 13 vs B 15	<0.05
B 15 vs R 13	<0.005
R 13 vs B'15	<0.01
B'15 vs R'14	<0.02
A 13 vs R 13	<0.9
R 13 vs R'14	<0.9

TABLE 29

Centrifuge Studies

HEART RATE RESPONSE TO +2.1 G_z FOR 670 SECONDS

(Beats/min)

Subject	Day of Study	Termination Time (seconds)	Baseline	Heart Rate Maximum (at ___ seconds)	Final	Reason for Early Termination
1	A 14	670	55	116 (600)	116	
	R 1	"	65	154 (670)	154	
	R 14	"	51	108 (420)	108	
	R'1 (with G suit)	"	50	104 (600)	100	
2	A 14	670	57	128 (540)	128	
	R 1	"	60	176 (540)	176	
	R 14	"	70	144 (420)	140	
	R'1 (with G suit)	"	60	146 (480)	140	
3	A 14	670	50	81 (600)	70	
	R 1	"	55	107 (600)	105	
	R 14	"	52	100 (600)	88	
	R'1 (with G suit)	"	50	90 (540)	82	

TABLE 29

Centrifuge Studies

HEART RATE RESPONSE TO +2.1 G_z FOR 670 SECONDS

(Beats/min)

Subject	Day of Study	Termination Time (seconds)	Baseline	Heart Rate Maximum (at ___ seconds)	Final	Reason for Early Termination
4	A 14	670	45	110 (670)	110	
	R 1	"	50	130 (660)	130	
	R 14	"	47	106 (660)	105	
	R'1 (with G suit)*	"	66	129 (660)	129	
5	A 14	670	46	100 (600)	88	
	R 1 (with G suit)	"	55	120 (600)	115	
	R 14	"	51	105 (660)	96	
	R'1	"	55	137 (660)	124	
6	A 14	670	65	140 (600)	135	
	R 1 (with G suit)	"	68	160 (420)	156	
	R 14	"	63	117 (540)	108	
	R'1	"	68	165 (670)	165	

*G suit spontaneously deflated early in this run.

TABLE 30

Centrifuge Studies

HEART RATE RESPONSE TO +3.2 G_z FOR 220 SECONDS

(Beats/min)

Subject	Day of Study	Termination Time (seconds)	Baseline	Heart Rate Maximum (at ___ seconds)	Final	Reason for Early Termination*
1	A 14	220	60	148 (220)	148	
	R 1	"	65	176 (150)	176	
	R 14	"	50	132 (150)	132	
	R'1 (with G suit)	"	50	126 (180)	120	
2	A 14	220	51	168 (180)	168	
	R 1	215	53	184 (90)	184	PLL, nausea
	R 14	220	50	172 (150)	172	
	R 1 (with G suit)	"	52	176 (120)	176	
3	A 14	220	58	103 (220)	103	
	R 1	"	62	137 (220)	137	
	R 14	"	55	110 (180)	108	
	R'1 (with G suit)	"	51	105 (210)	101	

*PLL = Peripheral light loss.

TABLE 30

Centrifuge Studies

HEART RATE RESPONSE TO +3.2 G_z FOR 220 SECONDS

(Beats/min)

Subject	Day of Study	Termination Time (seconds)	Baseline	Heart Rate Maximum (at ___ seconds)	Final	Reason for Early Termination*
4	A 14	220	45	138 (220)	138	
	R 1	"	50	150 (170)	142	
	R 14	"	43	125 (210)	124	
	R'1 (with G suit)	"	52	138 (150)	138	
5	A 14	220	48	125 (188)	124	
	R 1 (with G suit)	"	50	117 (185)	112	
	R 14	"	44	120 (185)	120	
	R'1	"	60	143 (185)	140	
6	A 14	206	75	168 (120)	165	PLL, CLL
	R 1 (with G suit)	220	72	172 (150)	170	
	R 14	167	50	165 (120)	165	PLL, CLL, LOC
	R'1	168	80	176 (120)	175	CLL

*PLL = Peripheral light loss.

CLL = Central light loss.

LOC = Loss of consciousness.

TABLE 31

Centrifuge Studies

HEART RATE RESPONSE TO +3.8 G_z FOR 185 SECONDS

(Beats/min)

Subject	Day of Study	Termination Time (seconds)	Baseline	Heart Rate Maximum (at ___ seconds)	Final	Reason for Early Termination*
4	A 14	185	65	143 (150)	137	
	R 1	"	55	155 (120)	153	
	R 14	"	45	135 (150)	134	
	R'1 (with G suit)	"	59	155 (150)	155	
5	A 14	185	55	148 (185)	148	
	R 1 (with G suit)	"	50	140 (185)	140	
	R 14	"	45	137 (185)	137	
	R'1	"	60	165 (185)	165	CLL
6	A 14	1	84	166 (0)	166	PLL, CLL
	R 1 (with G suit)	165	68	180 (150)	180	PLL, CLL
	R 14	69	56	170 (69)	170	PLL, CLL
	R'1	41	80	190 (41)	190	CLL

*PLL = Peripheral light loss.

CLL = Central light loss.

Table 31

Subject	Day of Study	Termination Time (seconds)	Baseline	Heart Rate Maximum (at ___ seconds)	Final	Reason for Early Termination*
1	A 14	185	55	156 (185)	156	
	R 1	130	70	176 (120)	176	PLL, PVC, nausea
	R 14	185	60	144 (185)	144	
	R'1 (with G suit)	"	50	136 (150)	132	
2	A 14	185	50	184 (180)	184	
	R 1	42	75	176 (42)	176	CLL, nausea
	R 14	133	60	188 (133)	188	PLL
	R'1 (with G suit)	144	75	" (90)	"	PLL, pain
3	A 14	185	75	104 (185)	104	
	R 1	"	57	157 (")	157	
	R 14	"	50	137 (180)	137	
	R'1 (with G suit)	"	"	125 (185)	125	

*PLL = Peripheral light loss.

CLL = Central light loss.

PVC = Premature ventricular contraction.

Table 32

Maximum Heart Rate During Centrifuge Studies
Group Means ±S.E.(95%)
(beats/minute)

Day of Study	Rest	$+2.1\ G_z$	$+3.2\ G_z$	$+3.8\ G_z$
A 14	53 ±7.9	112 ±22	142 ±27	150 ±28
BR-	59 ±7.1	143 ±22	161 ±21	169 ±14
BR+	58 ±3.2	124 ±36	139 ±12	147 ±26
R 14	56 ±9.3	113 ±17	137 ±16	152 ±23

P Values

R14 vs A14	<0.4	<0.95	<0.3	<0.95
BR- vs A14	<0.005	<0.001	<0.005	<0.10
BR- vs R14	<0.4	<0.005	<0.005	<0.05
BR+ vs A14	<0.3	<0.2	<0.6	<0.7
BR+ vs R14	<0.6	<0.4	<0.7	<0.7
BR+ vs BR-	<0.9	<0.05	<0.05	<0.05

+ With G-suit.

- Without G-suit.

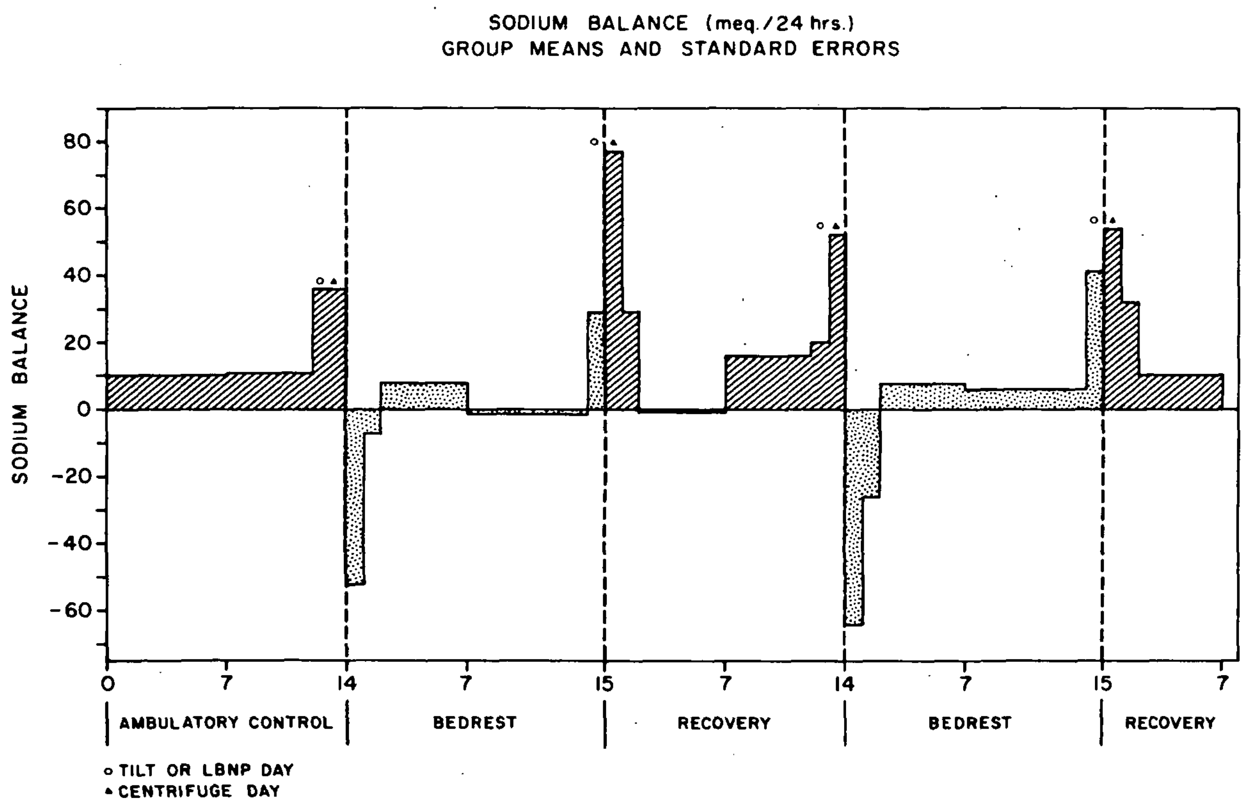

Figure 1

Sodium Balance. Group means on specific days or in specific periods of the study.

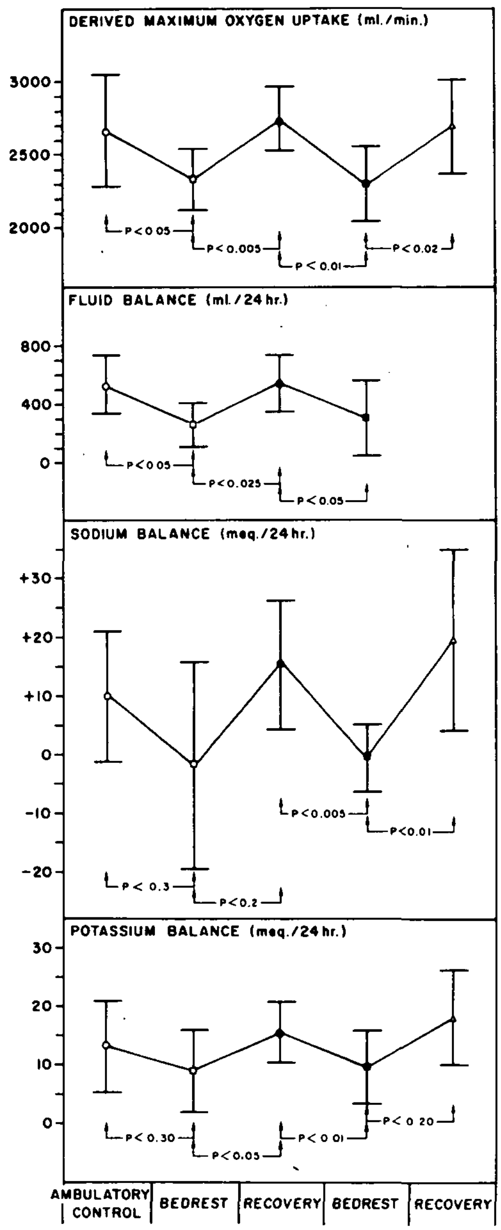

Figure 2

Sodium Balance, Potassium Balance, Fluid Balance and Derived Maximal Oxygen Uptake. Group means and standard errors.

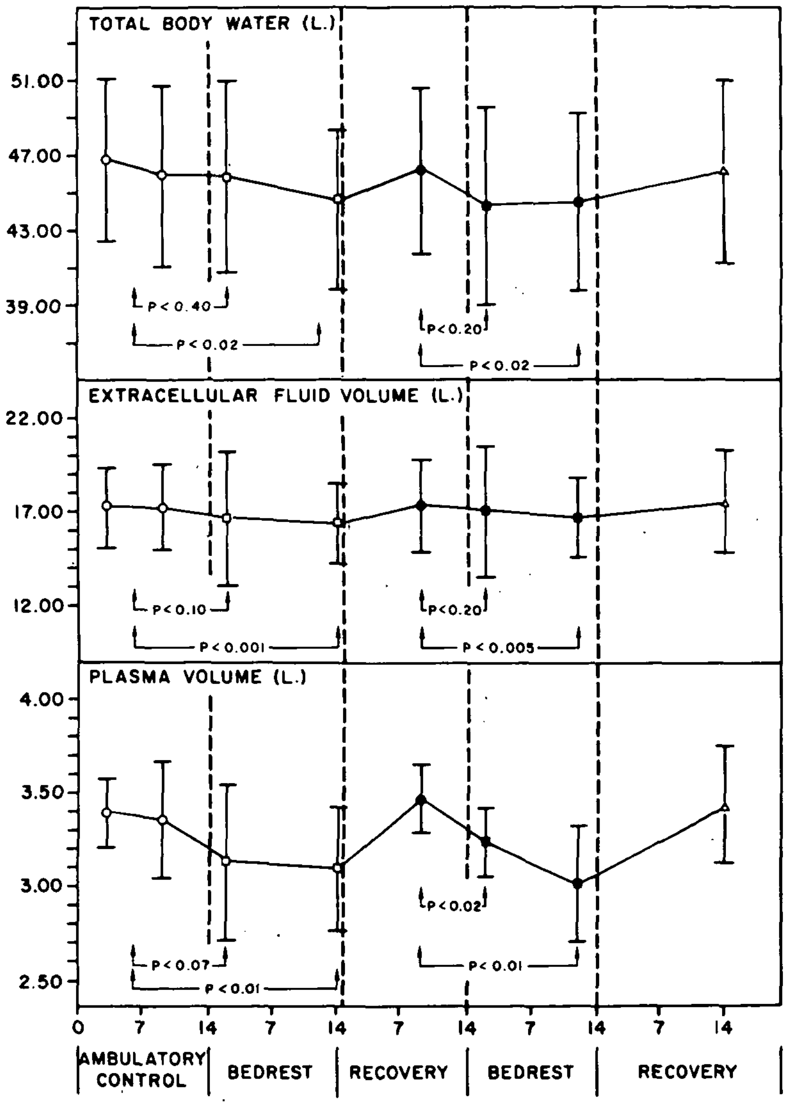

Figure 3

Body Fluid Compartments. Group means and standard errors on specific study days.

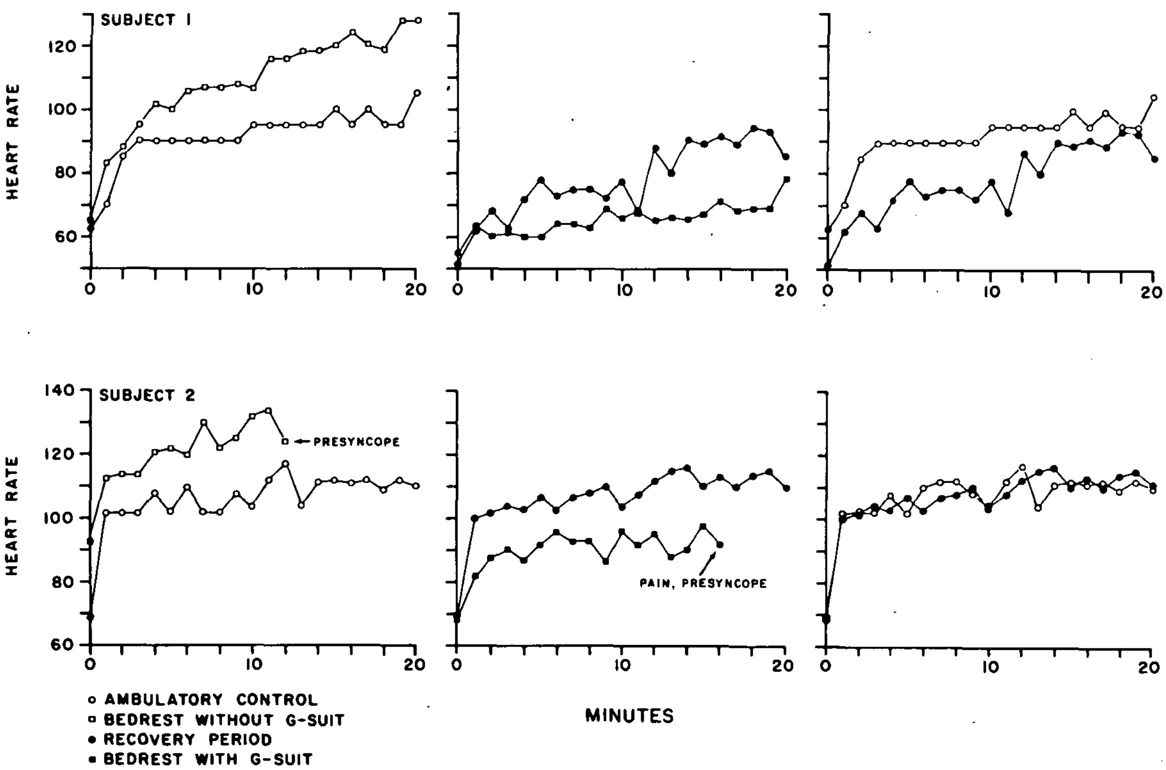

Figure 4

4. Heart Rate Responses to 70° Tilt (+1 G_z). Subjects 1 and 2.

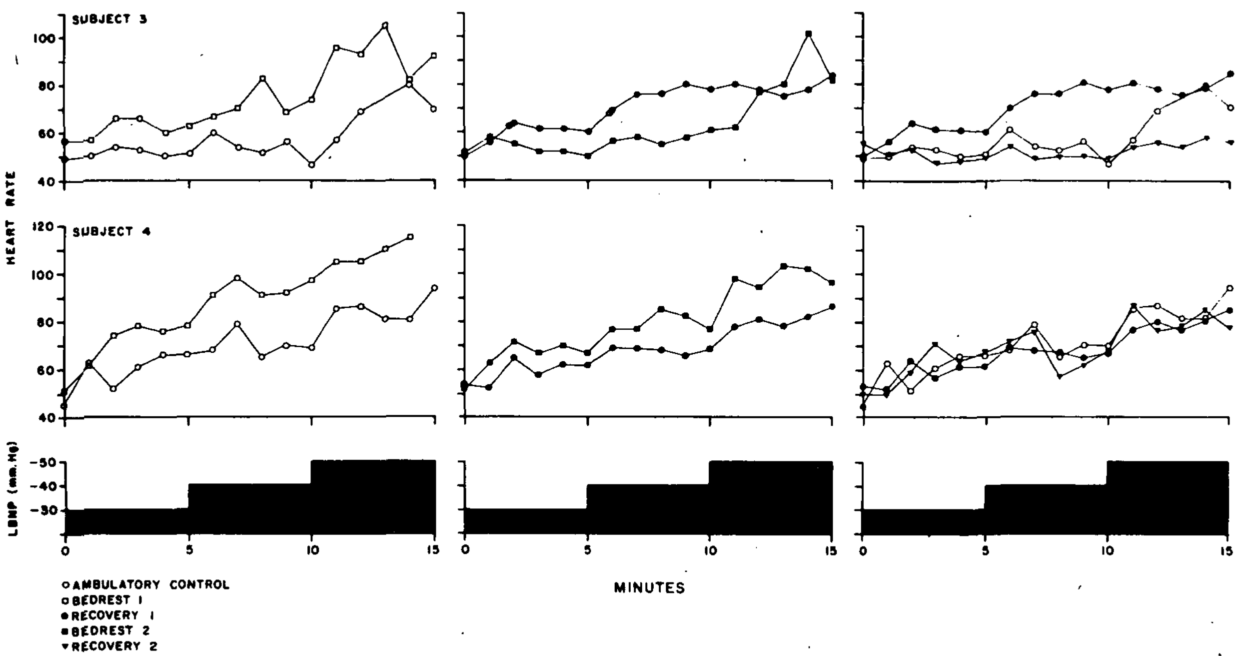

Figure 5a

Heart Rate Responses to LBNP.

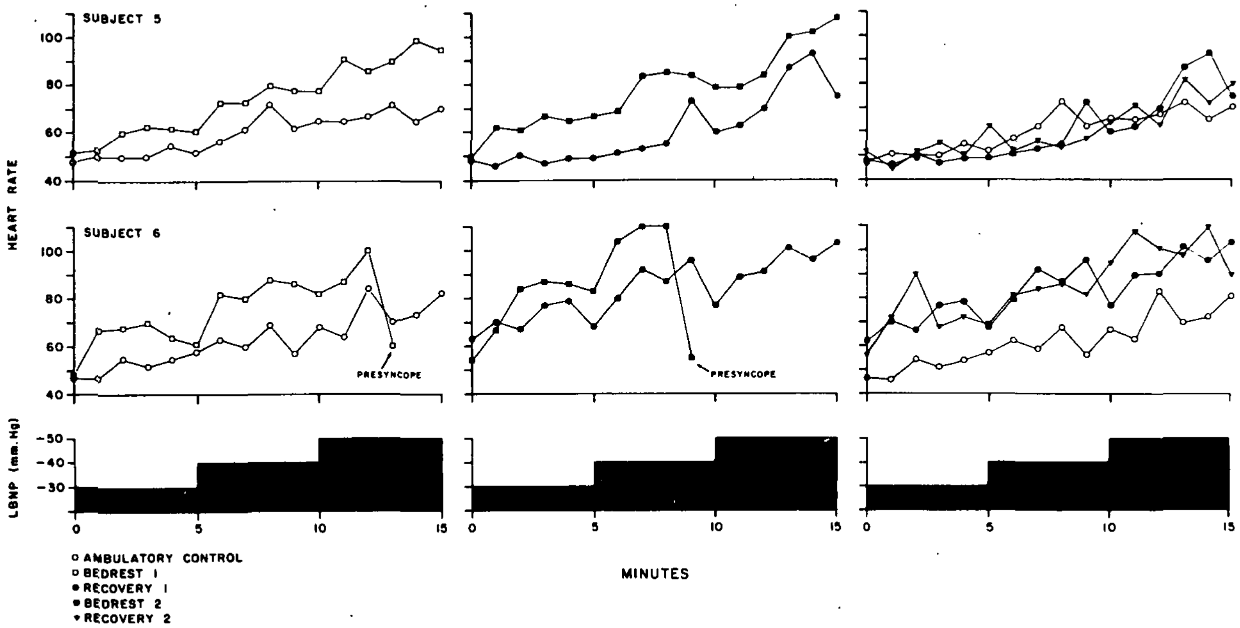

Figure 5b

Heart Rate Responses to LBPN. Subects 3, 4, 5, and 6.

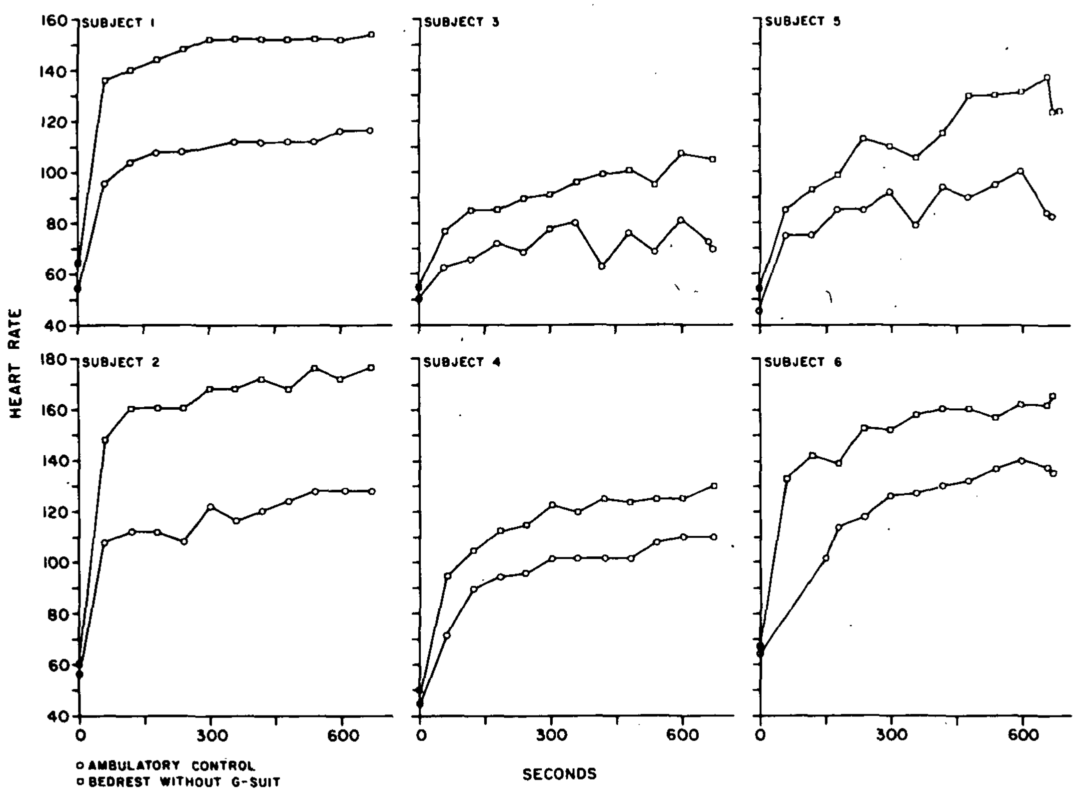

Figure 6

Heart Rate Responses to +2.1 G_z. Bedrest <u>without</u> G-suit and ambulatory control runs in all subjects.

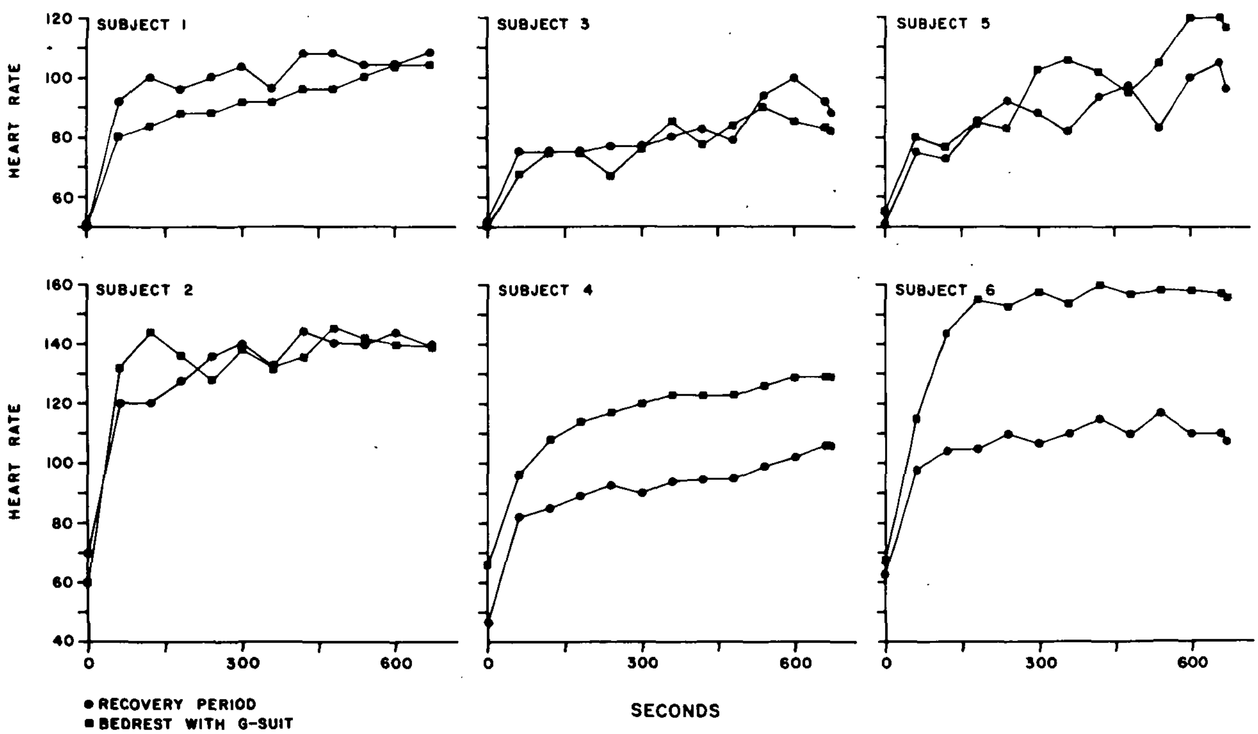

Figure 7

Heart Rate Responses to +2.1 G_z. Bedrest <u>with</u> G-suit and recovery period runs in all subjects.

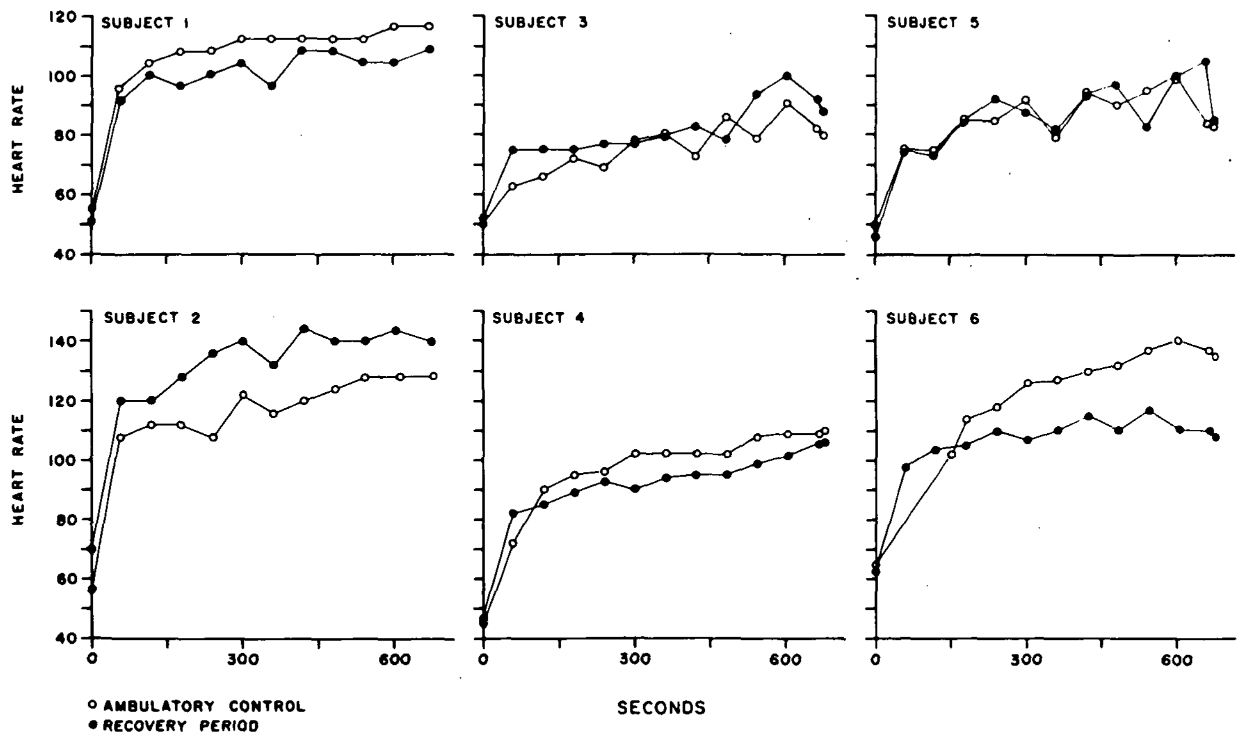

Figure 8

Heart Rate Responses to $+2.1\ G_z$. Ambulatory control and recovery period runs in all subjects.

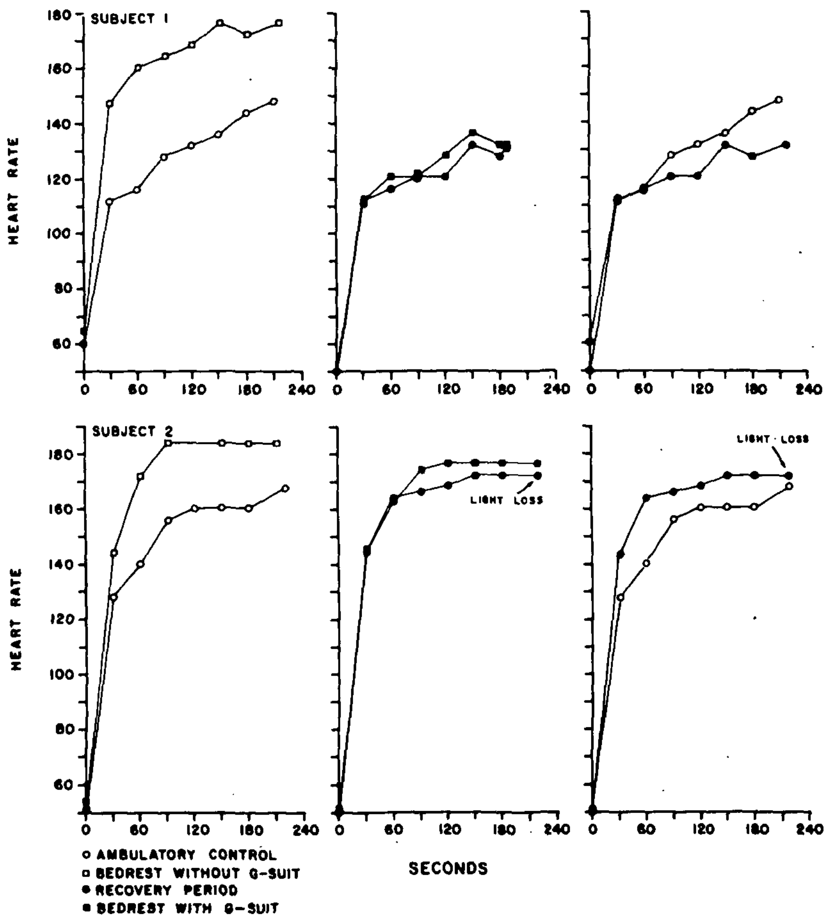

Figure 9a

Heart Rate Responses to $+3.2G_z$. Subects 1 and 2.

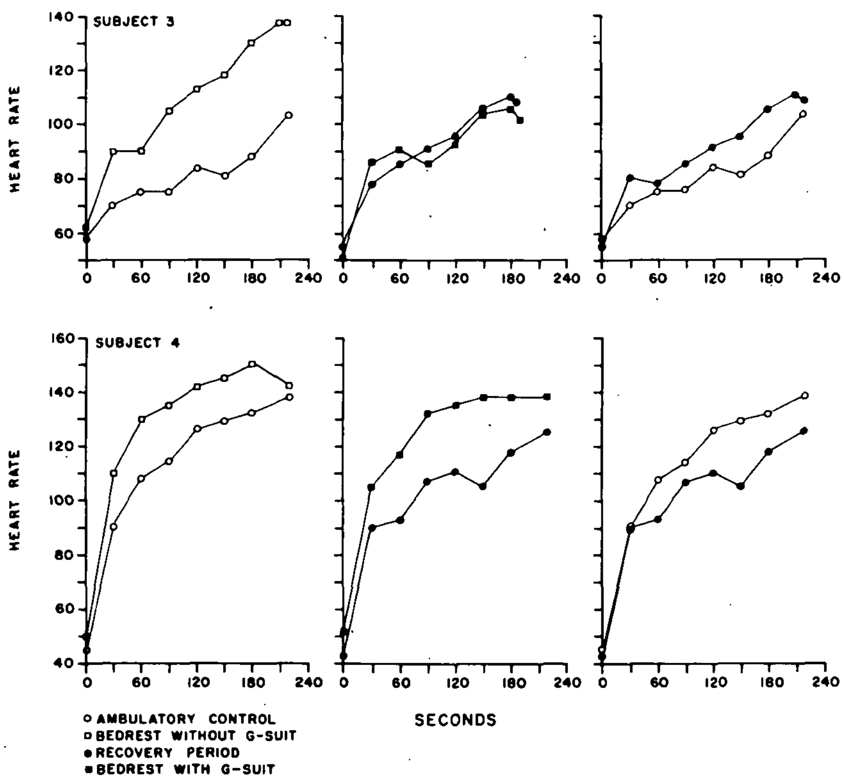

Figure 9b

Heart Rate Responses to +3.2G_z. Subjects 3 and 4.

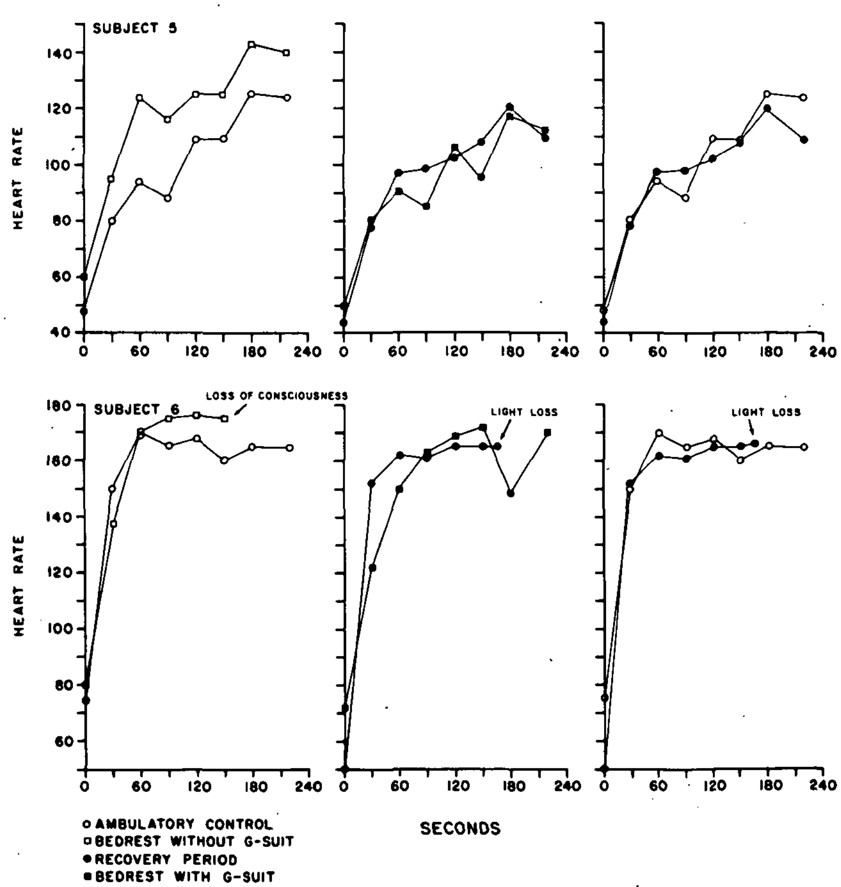

Figure 9c

Heart Rate Responses to $+3.2G_z$. Subjects 5 and 6.

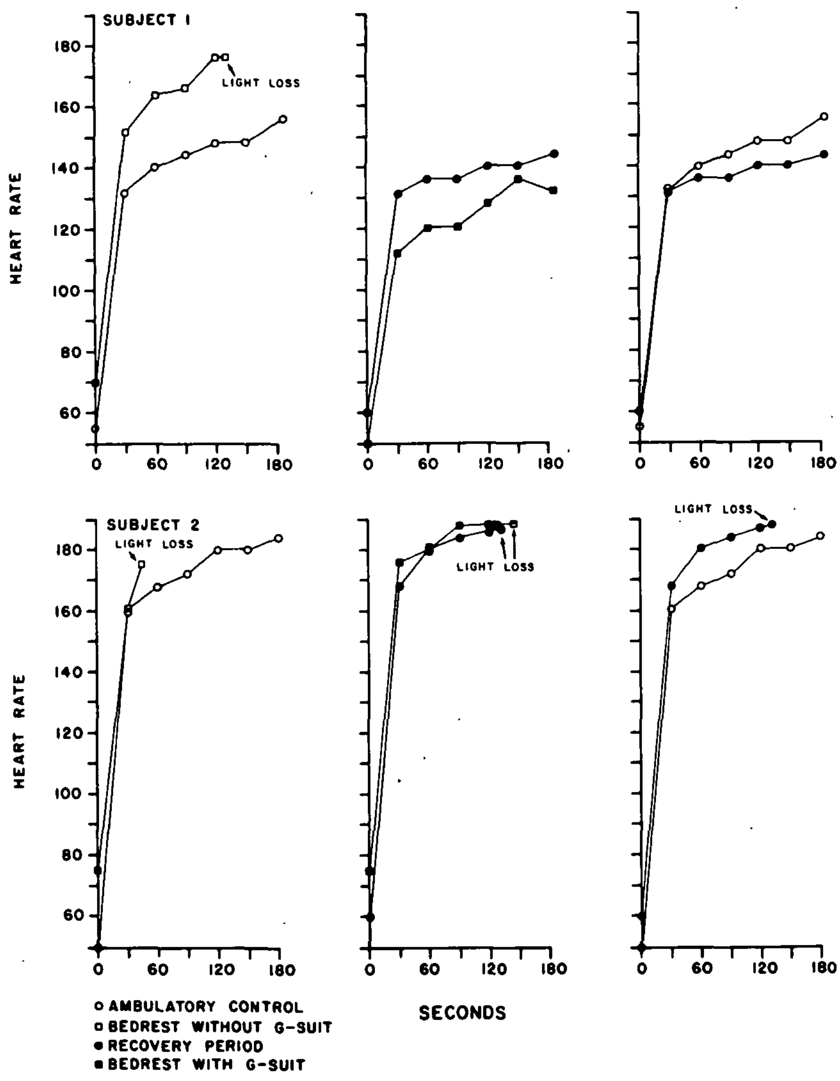

Figure 10a

Heart Rate Responses to +3.8 G_z. Subjects 1 and 2.

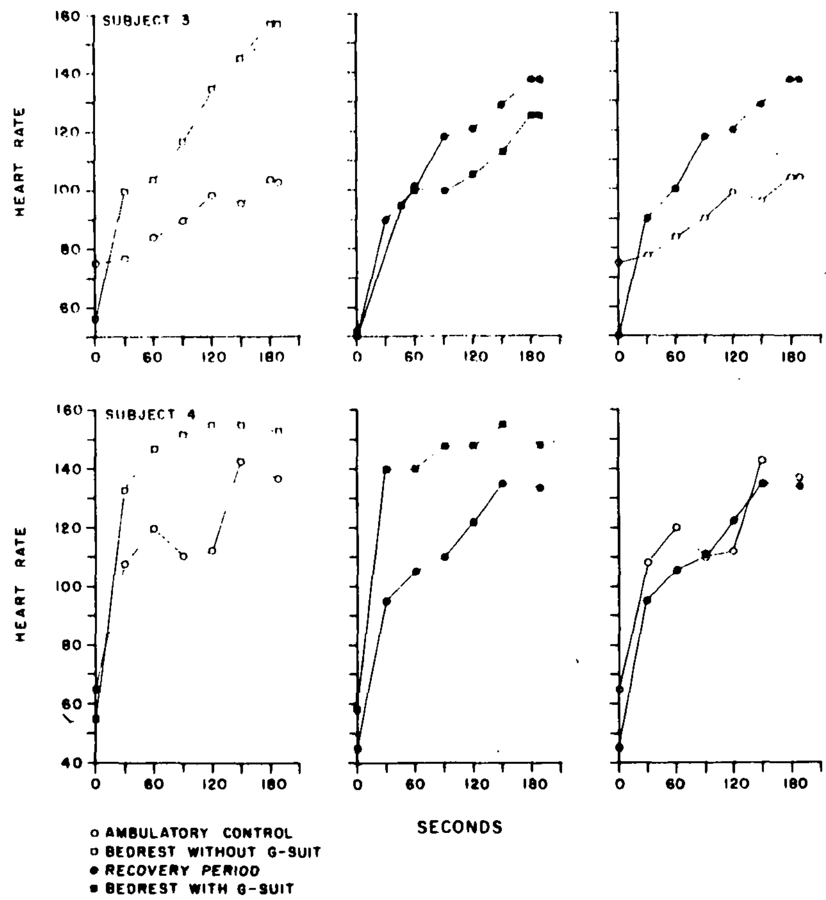

Figure 10b

Heart Rate Responses to $+3.8\ G_z$. Subjects 3 and 4.

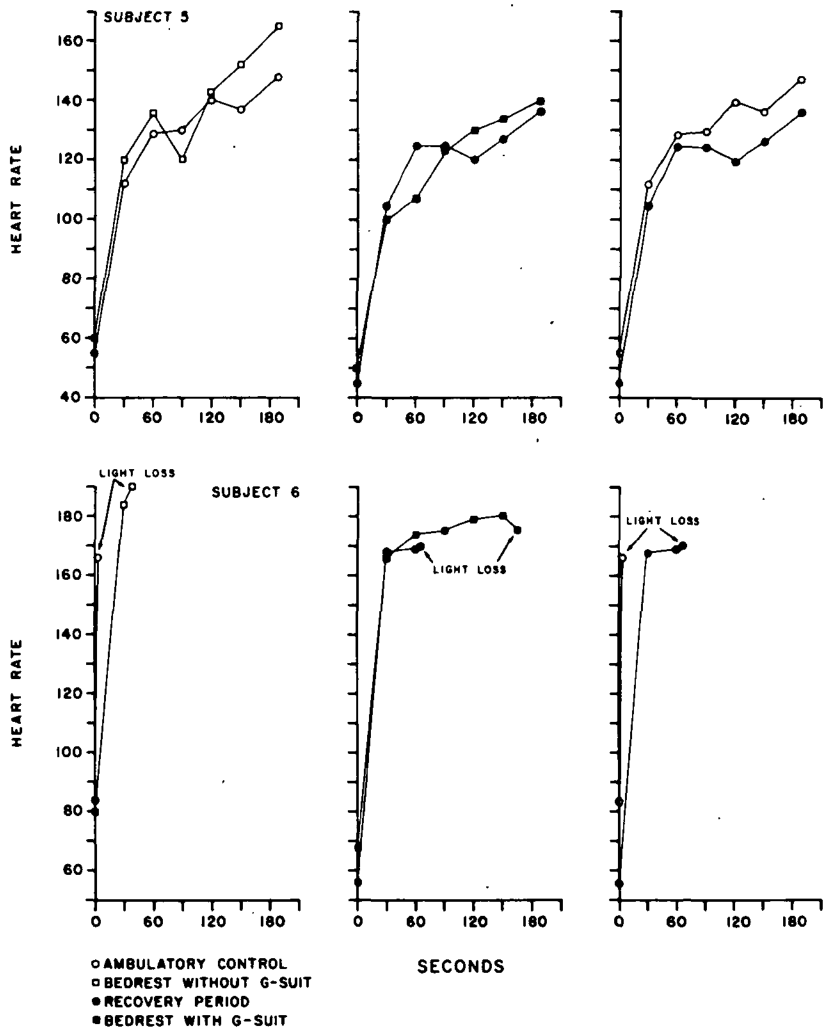

Figure 10c

Heart Rate Responses to +3.8 G_z. Subjects 5 and 6.

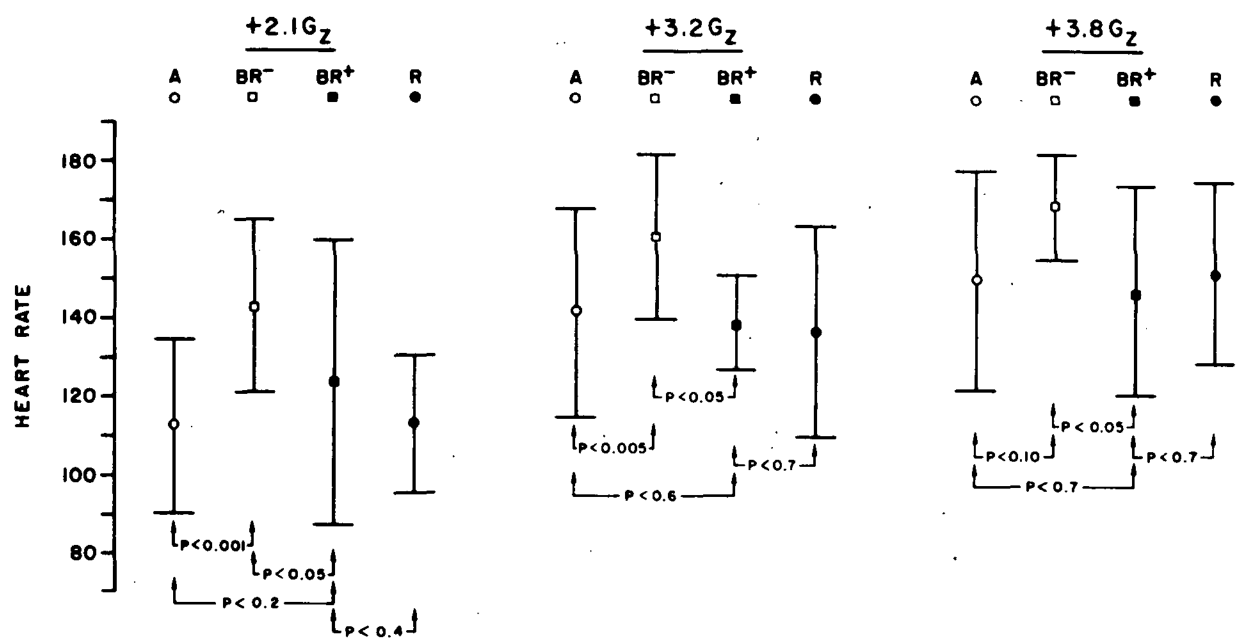

Figure 11

11. Maximum Heart Rates During Centrifugation. Group means and standard errors.